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Characterizing sub-surface microclimates used by a climate-sensitive species, the American pika

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Characterizing sub-surface microclimates used by a climate-sensitive species,
the American pika

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Abstract

The American pika is uniquely constrained to habitats of blocky debris. In this habitat, the availability of temperate sub-surface microclimates allows this temperature-sensitive species to survive the variable conditions of surface climate. The effect to which surface heterogeneity can influence the temperature regimes of the talus sub-surface has yet to be fully understood and previous studies have relied solely upon metrics of surface climate to estimate suitable habitat and future pika range. Here, I characterized sub-surface temperatures relative to elevation, aspect, near-surface temperature and microhabitat features such as talus depth and canopy cover to begin understanding the extent to which different surface features can affect pika habitat. Talus temperatures were found to be significantly affected by elevation, aspect, depth of sub-surface habitat, and a temperature sensor's placement overwinter, which was between talus, the talus interface, and the adjacent area of meadow or canopy cover.

Table of Contents

Introduction

Ochotona princeps (the American Pika) is an alpine-adapted lagomorph exclusively adapted to the microclimates of blocky debris. Rather than burrowing, pikas utilize the sub-surface voids found within boulderfields to find shelter and protection from harsh surface climates. The less-variable temperatures and relief from inclement weather found within these microclimates permit pika to survive in areas where surface conditions would otherwise not allow for their survival (Smith 1974). In times of thermal stress, the ability of pika to access these microclimates to regulate their body temperature ultimately determines the habitability of a site (Smith 1978). The current analysis investigates whether temperature differences between the near-surface and sub-surface of talus can be attributed to differences in surface features, such as elevation, aspect, canopy cover, and the presence of flowing water. While most predictions for the pikas' future are based upon correlative studies relating metrics of surface climate with data on pika persistence, presence, or absence, few have focused upon factors influencing sub-surface microclimates and the ability of a talus to allow for effective pika thermoregulation. Characterizing what determines temperature regimes in these sub-surface environments represents a step toward developing more complete and mechanistic models to predict future pika persistence.

In the summer of 2013, I placed multiple temperature sensor transects in the Indian Peaks Wilderness to determine the influence of surface features on near-surface and sub-surface temperatures. The features I focused upon were elevation, aspect, canopy cover, talus depth, and presence of flowing water beneath the talus. I predicted: 1) There would be a negative correlation between temperature and elevation, resulting in higher elevation taluses being the coldest; 2) The influence of slope aspect on incident sunlight would result in colder taluses on northern slopes; 3) Canopy cover would shade taluses from incident sunlight, resulting in cooler near-surface and sub-surface talus temperatures, and 4) The presence of water under the talus would buffer sub-surface talus temperature variation due to the additional heat capacity of humid air. If surface features significantly alter the near-surface and sub-surface temperatures of the talus, they may also determine which taluses may be the most conducive to pika survival.

I also studied overwinter (2013-2014) temperatures within the same taluses studied in summer 2013. Overwinter, I compared temperatures along transects spanning talus and adjacent habitats. Sensors were placed in sets of three, with one at the near-surface of the talus, one at ground level in the adjacent meadow or forest, and one at the talus-meadow (or talus-forest) transition. Transects differed in elevation, aspect and canopy cover, as well as duration of snow cover. I predicted (1) that the reduction in convective heat loss and additional heat storage vegetation provides would cause canopy-covered surfaces to be warmer than meadow surfaces and (2) that the air-filled voids within the talus would cause talus surfaces to exhibit significantly different overwinter temperatures than those of adjacent meadows or canopy covered surfaces.

This study was conducted over the course of my senior year at the University of Colorado at Boulder, with the intentions of fulfilling the requirements to graduate with honors in the Environmental Studies Department. I have provided figures of my findings as well as additional data summaries in the appendix of this paper, in the hopes that this can be stepping stone for future research regarding the habitat and persistence of pikas in the Colorado Front Range.

Background

By the end of the century, average global temperatures are expected to rise above pre-industrialized levels by at least 2°C (IPCC, 2013). The majority of this change is expected to be concentrated in arctic and alpine ecosystems (Fountain et al., 2012), negatively affecting their cold-adapted biota (Walther, et al., 2002). One such species that has undergone documented range retraction in response to climate change is the American Pika (Beever et al., 2003; Holtcamp, 2010; Ray et al., 2012). These diurnal lagomorphs are alpine specialists that inhabit blocky debris above 2,500m and thrive in the fragmented talus and mining debris of high elevation mountains (Beever & Smith, 2011; Smith, 1974a; Smith & Weston, 1990). Like other lagomorphs, pikas do not hibernate. In order to survive in the alpine, pikas have adaptations to deal with the region's extended winters and cold, which unfortunately may make the species more susceptible to climate change. A pika's extremely high basal metabolic rate, 143% of a predicted weight-specific value for the species (MacArthur & Wang, 1973), is crucial in allowing them to survive under the snowpack but quickly induces lethal hyperthermicity during short periods of 25.5-29.4°C (Smith, 1974a). To mitigate heat gain during days of heat stress, pikas will use short bursts of activity followed by a retreat into the cooler sub-surface to "shed heat" and remain within tolerable body temperatures (MacArthur & Wang, 1974). In the winter, sub-surface habitats are shielded from the extreme cold of the surface and will remain around 0°C when covered in sufficient snow (Beever et al., 2010). Thus, access to sub-surface habitats that are relatively cool in summer and relatively warm in winter may be fundamentally important in determining which taluses are most conductive for pika survival. Typically, debris 0.2 to 1.0 meter in diameter provides the space needed for mobility within sub-surface voids (Beever & Smith, 2011), but in a warming climate sub-surface shelter alone may be inadequate in shielding pikas from warmer temperatures (Holtcamp, 2010; Ray et al., 2012).

Pikas are vigorously territorial and stake claims throughout the talus (Smith & Ivins, 1986). Claims are regularly spaced, though differences in size can be attributed to talus configuration, distance to, and quality of the nearest vegetation. A pika will defend 55% of the territory covered by its daily movements (Smith & Irvins 1986) and will usually settle next to territories of the opposite sex (Smith & Weston, 1990). Within their territories, pikas have adapted to surviving alpine winters by "haying" or caching food under overhanging rocks during summer. Haying occurs between July and September, starting with the timing of peak vegetation in the alpine (Millar & Zwickel, 1972). Collected vegetation is stored in "haypiles", situated under large rocks near the talus interface. At my study site, it has been shown that pikas predominantly feed on gramminoids (e.g., grasses) during the summer, but cache forbs (flowers and woody plants less palatable than gramminoids) for overwinter consumption (Huntly et al., 1986). The pika's selection of less palatable foods for winter storage may be due to their better storage quality (Dearing, 1997a; 1997b). Toxins that initially make forbs less digestible can deter bacterial growth and decomposition in the haypile, prolonging their "shelf life". If the toxins in haypile vegetation have not degraded enough to be palatable, pikas will supplement their diet from grazing beneath the snowpack (Dearing, 1997a).

In a changing climate, the quality of pika habitat will likely become increasingly important. The effects of climate change will probably be felt first and most on the surface, and it is not clear how sub-surface microclimates will respond to these changes in surface climate. Quality taluses will have surface features that contribute to a pika-friendly microclimate, where readily accessible areas of different temperature will allow pikas to effectively thermoregulate. The effect of elevation and aspect on surface temperature is well known, whereas the extent to which these factors affect sub-surface microclimates has yet to be subject to much scientific research. Within taluses, some territories may be more suitable than others on the basis of features like talus depth, canopy cover, and the presence of flowing water beneath the rocks. Temperature should drop within deeper voids of the talus as well as be cooler in the areas covered by a canopy. Flowing water may act to shield sub-surface voids from temperature variation in the way humidity buffers maritime climates from large seasonal changes. Current literature offers little on how habitat quality can vary within and among pika territories, so here I have studied summer and overwinter sub-surface temperatures to begin moving research in this direction.

Methods

For this study, I sampled temperature transects at three research sites: north-, south-, east-, and west-facing slopes on the West Knoll of Niwot Ridge (WK), the north-facing slopes above Long Lake (LL), and the south-facing slopes above Mitchell Lake (ML) in the Colorado Front Range. The WK was the highest of these sites and situated within the Niwot Ridge Biosphere Reserve, above the University of Colorado at Boulder's Mountain Research Station. At ~3600 m, the WK was the only site above treeline. LL and ML were within the Brainard Lake Recreation Area, the watershed just north of Niwot Ridge. The sampled taluses surrounding LL and ML lie ~300 m lower than the taluses of WK and are situated on opposing sides of the valley, allowing for comparisons of elevation and aspect.

I first collected data in summer of 2013 and during this time I focused my research upon the effects of elevation, aspect, and different surface features (canopy cover, open talus, and flowing water within the talus) on near-surface and sub-surface temperature regimes of the talus. Transects were made corresponding to the diagram in Figure 1. Each transect was comprised of 3 temperature sensor pairs, where a pair was comprised of one near-surface sensor covered by rocks (to prevent inflated readings from direct sunlight and interference from passersby or animals) and one sub-surface sensor, placed as deep as it was possible to dig (ranging 30 to 150 cm). Sub-surface placement necessitated the removal and replacement of the rocks directly below the surface sensor, which may have changed the original configuration of the talus; however, I attempted to replace rocks in their original configuration. I used Onset HOBO Pro Series data loggers with 5-minute resolution for each placement throughout the study. On the WK, I established four transects corresponding to each cardinal direction. Sensor pairs in each transect were spaced 10 meters apart for a total transect length of 30 meters. LL and ML transects focused upon effects of surface features and were aligned so sensor pairs could be placed within areas of canopy cover (CC), water flowing beneath the talus (WU), and open talus (OP) with no sub-surface water flow. Distance between sensor pairs varied between 15 meters and 50 meters. Sensors were placed in late July and were in place for a minimum of nine days.

In November 2013, I returned to WK, LL, and ML for the placement of data loggers to measure overwinter temperatures at the surface of the talus or ground (often beneath the surface of accumulated snow). Due to the longer in-situ period, resolution was adjusted to 1-hour readings. Transects were comprised of three surface or near-surface sensors and were centered at the edge of a talus patch, at the interface between talus and meadow or talus and forest (Figure 2). Each transect extended 5m to either side of the interface, allowing for the measurement of temperatures in the interior of the talus and in the meadow or canopy covered area adjacent to the talus patch, as well as the interface itself. Temperature-only sensors were used on transect ends while the sensor at the center of the transect measured both temperature and light intensity, allowing for an estimate of the timing of snow melt via recorded light intensity readings. ML and LL sites had at least two transects (ML = 2, LL = 4), where one represented talus to meadow surface temperatures and one represented talus to canopy-covered surface temperatures. Since WK was above treeline, transects here were placed on opposing slopes (northern vs. southern) to demine if aspect influences alpine overwinter temperatures near the talus or ground surface. As with the previous placements, sensors were shaded from direct sunlight using local rocks.

Analyses were conducted in Microsoft Excel using $\alpha = 0.05$ as the significance level with Bonferroni correction for multiple comparisons. My analysis of summer data focused on comparing near-surface and sub-surface temperature metrics (mean, maximum and minimum temperature) with respect to surface features. ANOVA was used to determine the influence of surface features on observed temperatures, and linear regression was used to model observed temperatures as a function of depth under the talus. For overwinter data, I summarized higher and lower temperatures as the number of days above or below a threshold temperature, in place of maximum and minimum temperatures, to avoid the influence of anomalous temperatures during the long time series and to characterize the data in terms of physiological constraints hypothesized for pikas (pikas may survive an occasional warm or cold day, but may not be able to tolerate long periods above or below certain threshold temperatures). Thresholds were set at 25°C and -10°C, similar to the upper and lower lethal temperatures indicated in pika literature (Smith and Weston 1990, Beever et al. 2010, Wilkening et al. 2011). For these metrics, I counted each individual measurement that corresponded to an hour above 25°C or below -10°C and summed the results into a total number of hours that could induce thermal stress on the pika. I also calculated the coefficient of variation in temperature for taluses, talus interfaces, and meadow/canopy-covered areas to determine if the size of temperature fluctuations differed across surface types.

Results

Summer Temperatures, 2013

Of the 36 individual temperature sensors deployed in the summer of 2013, seven failed to collect data for analysis. Table 1 of the appendix summarizes the maximum, minimum, and mean temperatures recorded by near-surface and sub-surface sensors for each location. After removing sites where one or both sensors failed, sub-surface temperatures were significantly cooler than near-surface temperatures during my summer study period (one-tailed, paired t-test, $N=12$, $p<0.001$). A similar result (Figure 3) was supported by an unpaired t-test of all summer sensor data, before removing sensor pairs with missing data (one-tailed, unpaired t-test, surface $N=15$, sub-surface $N=14$, $p<0.001$). Maximum and minimum temperatures of sub-surface placements at each site were more moderate than those of near-surface placements (Figure 4). Across all sites, mean daily sub-surface maximum temperatures (12.19°C) were on average 11.28°C colder than mean daily near-surface maxima, and mean sub-surface temperatures (23.48°C) were 3°C cooler than mean near-surface temperatures (7.21°C). In addition, mean daily sub-surface minima (4.51°C) were 0.72°C warmer than those of mean daily near-surface minima (3.79°C). Together, these measured sub-surface patterns produced a 5.96°C smaller range in temperatures (range= 20.32°C) relative to the near-surface (range= 26.28°C). After removing an outlier in the data from LL (where a sensor placed over running water recorded anomalously high temperatures), the difference in range of sub-surface vs. near-surface sensors increased to 9.79°C. When surface temperatures exceeded the pika's putative threshold for heat stress (temperatures >25°C), the sub-surface always remained within temperatures tolerable for a pika and would have provided an effective thermal refuge.

Figure 5 shows the in-situ temperature/time charts of selected near-surface and sub-surface sensors representing each placement type. From this, it can be seen just how much the microclimates of the sub-surface can differ from place to place. Sub-surface temperature regimes varied from mirroring near-surface temperature with only a few degrees of difference in cooling (WK N1 and LL CC; note LL CC's higher maximum sub-surface temperature relative to near-surface maximum in figure 4) to stable colder temperatures (ML WU and ML OP). Much of this difference can be attributed to the depth of sub-surface sensor placement: mean temperature declined significantly with sub-surface sensor depth (single linear regression of mean sub-surface temperature on sensor depth, $y=-5.96x + 10.71$, $p<0.001$, $r^2= 0.77$; Figure 6).

Higher elevation was correctly predicted to result in colder taluses, as WK sites were 2.4°C colder in mean subsurface temperatures than their LL and ML counterparts (one-tailed, unpaired equal variance t-test, WK N= 9, ML and LL N= 5, p= 0.0327). Temperatures tended to be colder on north- and west-facing slopes on the West Knoll, although no differences in mean, maximum or minimum temperatures were significant after Bonferroni correction for six comparisons (N-W, N-S, N-E, W-S, W-E and S-E, α = 0.05/6 = 0.008 for each temperature metric; Figure 7a-c).

CC taluses had 6.5°C colder maximum near-surface temperatures than OP taluses (one-tailed, unpaired equal variance t-test, CC N= 2, OP talus N= 2, p= 0.0962; Figure 7e) and CC and WU taluses combined had 1.45°C cooler minimum sub-surface temperatures then OP talus (one-tailed, unpaired equal variance t-test, WU & CC N= 3, OP talus N= 2, p= 0.0548; Figure 7f). Considering these two results, it would seem that canopy cover and sub-surface water may provide some sheltering effects from heat-induced thermal stress on the pika, although mean temperatures did not differ significantly between OP, WU and CC sites.

Linear regression and analysis of variance showed sensor position to have the largest influence on maximum temperature while minimum temperatures were most influenced by elevation and aspect. Surface placements corresponded to the highest maximum temperatures while the lowest minimums occurred on high-elevation northern slopes. Since the mean was most influenced by the maximum temperature, as maxima were the most variable and different from the other temperatures, it also was largely determined by either surface or sub-surface placement. For example, the highest surface maximum paired with the highest mean surface temperature and both occurred in open talus at Long Lake. Figure 8 shows a model of position, elevation, and aspect (North versus South or East and West) to predict observed mean temperatures, which explained 66% of the variance (multiple linear regression, $p < 0.001$, $r^2 = 0.66$). Using data from N = 9 sub-surface sensors placed on the West Knoll, mean temperature was well explained by sensor depth in a linear regression ($p < 0.001$, r2 = 0.77). Here, mean temperature dropped 5.96°C per meter of depth.

Overwinter temperatures, 2013/2014

Overwinter measurements focused on differences in surface temperature between open/mid talus, talus edge/interface, and the adjacent meadow or forest. There was a non-significant trend toward warming from talus to meadow for all but one transect (Fig. 8). This outlier in the lower LL Meadow transect is likely due to the placement of the sensor in an especially wind-scoured area. Snowcover data from the talus interface sensor shows multiple periods of exposure. Wind scouring would remove any insulation snowcover could provide and cause the sensor's mean temperature to reflect the colder mean air temperature rather than the temperature at the bottom of the snowpack. After excluding data from this outlier, the warming trend from open/mid talus to the meadow became significant (one-tailed, paired t-test, talus N=4, meadow N=4, p= 0.0180). Without removing the outlier, there was a significant warming trend from open/mid talus to talus edge/interface (one-tailed, paired t-test, talus N=5, talus interface N=5, p= 0.0075), and this portion of the transect accounted for a 0.72°C rise in mean temperature. No significant rise in temperature was detected between talus edge/interface and meadow.

Across CC transects the opposite occurred, where the open/mid talus surface was warmer than that of the CC surface. CC tended to cool surface temperatures by 1.14°C on average, though the statistical significance of this was only marginal (one-tailed, paired t-test, talus N =3, p= 0.0684). No significant difference in temperature was found between the talus edge/interface and either the open/mid talus or CC surface locations, although CC locations had the highest temperatures when disregarding the LL CC high transect (again this sensor was likely in an area subject to wind scouring of snow). Compared to meadow locations, CC surfaces were only slightly warmer (0.65°C), though this was an insignificant difference (one-tailed, paired t-test, N=3, p= 0.3863).

Six sites recorded temperatures above 25°C. At two of these, the sensor was in direct sunlight when removed in the spring (resulting in overestimated temperature values) while two others recorded anomalously high values (Talus and Talus Interface LL Meadow High sensors). At the remaining two sites (LL Talus Meadow Interface Low and ML Talus Canopy Cover Interface), temperatures above 25°C appear to be valid because near-surface sensors were still sufficiently covered with local rocks to prevent direct exposure to the sun at the time of removal. These two sensors recorded 13 hours of thermal stress, both of which occurred at talus interfaces at lower elevation LL and ML sites. The open and sunny LL sites, which had a northern aspect, contributed six >25°C hours, whereas seven >25°C hours were recorded at ML.

Temperatures below -10°C predominantly occurred at high elevation on the WK (one-tailed, unpaired equal variance t-test, WK N=6, LL and ML N=18, p= 0.0003). ML, LL and WK recorded 0, 5266.5 and 6319 hours of <-10°C temperatures, respectively. On the WK, sensors along the northern aspect transect recorded double the amount of cold hours as those along the southern transect (one-tailed, paired t-test, northern aspect N=3, southern aspect N=3, p= 0.0446). This trend continued at lower elevation sites, where all

5266.5 cold hours were recorded at the northern aspect LL study site. Within transects, no significant difference in the amount of cold hours between the open talus, talus interface, and meadow/canopy cover was detected.

Temperatures fluctuated more at the surface of open taluses than at meadow or canopy-covered locations. At LL, the coefficient of variation (CV) of surface temperature on open taluses was significantly larger than those of CC locations (-19.33 compared to -4.80, respectively; one-tailed, paired t-test, N=2, p= 0.0105) or both CC and meadow locations (one-tailed, paired t-test, N=4, p= 0.0390). Similar trends were not significant within the ML and WK sites, but after combining data from all three sites, open talus was again the most variable environment for temperature (one-tailed, paired t-test, talus N=8, meadow/canopy cover N=8, p=0.0408). Comparing Meadow to CC surface did not yield significant results either, although the range of meadow CV was larger then that of CC surfaces (12.73 compared to 4.41, respectively; one-tailed, paired t-test, N=3, p= 0.3701).

Melt-out dates were estimated using temperature/light sensors placed at talus interfaces. During the in-situ period, sensors under canopy cover were consistently covered by snow. Unlike the off/on burials of LL's meadow transects, LL CC transect interfaces were totally covered throughout winter months and recorded late melt-out dates, May 29th for LL CC high and June 2nd LL CC low. At ML, CC recorded low snowcover on June 23rd (ML) while its meadow companion was buried for the full in-situ period (it had to be dug out!). Although some WK and ML meadow-end sensors were still under remnant snow when I ended data collection, they likely would have been snow free in the following week (C. Ray, personal observation). The southern WK meadow sensor was one such sensor, which was placed in an area subject to high wind loading, resulting in a late (June 22nd) melt-out date. The corresponding WK northern transect fully melted out April 16th.

Discussion

Elevation is a well-known influence on environmental regimes and species composition (Merriam, 1894). The question with pikas in regards to climate change is how pikas will act to avoid warmer temperatures. Will they retreat up the mountain (Ray et al., 2012; Holtcamp, 2010)? Or will populations be lost due to the pika's poor ability to disperse (Smith, 1987)? Higher elevational taluses will be cooler in the summer than lower elevational ones, thereby offering a refuge to the pika that can inhabit them. Though I was unable to detect a significant difference between surface temperatures and elevation in my summer study, elevation did influence subsurface temperature. Comparing data among sub-surface sensors only, WK taluses were 2°C cooler than LL or ML sites and maximum temperatures were also lower by 6°C. With a larger sample size, a surface temperature trend may have been detected. Previous research on Niwot Ridge estimated a -0.71°C/100m lapse rate of surface air temperatures, where the difference in mean temperature during July at two research sites comparable to mine was 3.68°C (Greenland, 1989).

Considering only heat stress, the pikas' future may lie in finding cooler refuge at higher elevations. But, could there be an upper limit to the habitat in which pika inhabit? Movement to higher elevations will come at a cost, where larger proportions of the year will be dominated by winter. While snowfall and winter snow cover may be important to the pika's survival, long durations of snowcover limit the growing season for vegetation, leaving little food for pika grazing and little time for haying. Too little snowcover results in insufficient insulation from lethal <-10°C temperatures, meaning higher elevation refuges will have to have areas that are 'just right' in overwinter snowcover. When sufficiently covered with snow, the ground surface will be insulated from the colder air above and remain at 0°C (Elsner & Pruitt, 1959; Zhang, 2005). Beever et al. (2010) suggested that insufficient snow cover does contribute to pika decline, as adequately covered taluses were never subject to -22°C temperatures of uncovered extirpated sites. Considering the large amount of cold hours that the WK pika population already has to survive (6319 hours), any change in the amount of snowcover will likely have implications on their future persistence regardless of the summer habitability of the site.

Beyond the increased thermal stress climate change will induce on the pika, changes in the cryosphere will further complicate the ability of the species to seek refuge in higher elevations. Current warming has already resulted in a larger proportion of rain falling throughout the year than snow (Knowles et al., 2006), as well as initiating snowmelt two weeks earlier than what was recorded in the 1970s (NPS, 2007). If current outputs of greenhouse gas emissions do not change, snowmelt has the potential to shift another 30-40 days earlier in the year (Stewart et al., 2004). Even if snowfall were to increase throughout the intermountain west, this may not be enough to buffer the effect of a warmer climate. Temperature has been shown to be a more important factor in causing snowpack decline than changes in precipitation, where decreases in total snow accumulation have been documented even when significant increases in winter precipitation have occurred (Mote et al., 2005; Pierce 2008). Without a full duration of snowcover, pikas are more susceptible to late fall and early spring cold snaps and freezing rain, as well as the lethally cold temperatures that occur midwinter. When combined with warmer summer temperatures, this change may be driving the retreat of pika populations up the mountainside and into the “sky islands” of mountaintops (Holtcamp, 2010).

Further contribution of the cryosphere on the effectiveness of the sub-surface in providing a cooler microclimate may be the result of belowground permafrost. If this is to be the case on the WK, my summer 2013 data may show the cooling of the sub-surface talus environment when approaching the depth of permafrost. Referring to a linear regression of sensor depth and mean temperature ($N= 9$, $p <0.001$, $r2= 0.77$; Figure 6), where the line of best fit crosses the x-axis may be indicative of permafrost depth. Extrapolating this estimated permafrost depth during the study to be 1.8 meter.

Something else that came to my attention during the fieldwork of my study was the impact and heterogeneity of snow distribution. On the large scale, the difference between wind-scoured and wind-loaded snow zones is readably noticeable. But the effect to which differential snowcover had on the transect scale surprised me. During the removal of my sensors, the inconsistencies in which sensors were buried made any attempt to judge the date of snowmelt across the entire transect through the data of one talus interface sensor an unfeasible goal. The many irregularities in the surface of the talus environment resulted in numerous small-scale snow-scoured and snow-loaded zones that became significant in the spring. The WK south transect, for example, had a snow-free talus and talus interface sensor at the time of removal while the corresponding meadow sensor was buried and completely frozen into a layer of ice. Unbeknownst to me in the fall, the higher mound that comprised the talus acted to trap windblown snow and form a large drift directly on top of my meadow sensor. Though the talus was only higher than the meadow by about a meter, it was a large enough difference to drastically influence the accumulation of snow and melt out dates of individual sensors across the transect. Here, it is worthwhile to note that my overwinter study was conducted in a snow year that was among the highest on record in the past decade. The effect to which differential snowcover has on such small spatial scales in lower snow years would be interesting, as low snowcover could have produced different results. From previous experience on the WK, the difference between the peak accumulation of this 2013/2014 snow-year and the previous, well below average 2012/2013 snow-year, was drastic. Where snow was completely gone from the WK mid-June of 2013, patches of snow persisted throughout the month of July 2014.

Additionally, I found it interesting that for the southern WK transect's meadow sensor, its period of being frozen into the ice corresponded to its warmest temperature readings. Looking back through the sensor's temperature log revealed a progression of less variable temperatures across the winter, culminating to the point in which temperature reading alternated between reading of -0.61°C and -0.16°C. This began during the timing of snowmelt, May 20th, when water was likely flowing beneath the meadow snowpack from the melting talus mound above. Why it froze so completely and thick at the time of removal (the ice was about 5 cm deep and only a thin portion was liquid on the ground surface) could be due to the full melt-out of the talus above and termination of flowing melt water across the bottom of the snowpack (the talus was snow free at the time of removal). When this occurred, the slushy bottom of the snowpack was likely more prone to remaining fully frozen throughout the day. What this observation leads me to think is that the best insulation from overwinter temperature fluctuations and extremes is a surrounding layer of ice. For the pika, this may mean formation of ice layers in the snowpack above the talus surface could provide the most robust, isothermal insulation available overwinter. Perhaps sites where ice layers are more prone to forming within the snowpack are more inhabitable then those without, though the formation of these layers usually occurs in the late winter/early spring, when other factors are likely more determinant on pika survival.

Also worthy of notice was the surprising LL WU result, where I did not expect the large diurnal variations of sub-surface temperatures to occur. Due to the surface sensor failing at this site, my comparison to surface temperature relies on the nearby LL OP surface temperature data (Figure 5f). The dramatic warming events that produced the maximum temperature value of 23.63°C (3.82°C warmer then any other sub-surface maximum and 11.45°C warmer then the mean sub-surface temperature) occurred multiple times and lasted several hours. Each time, the sub-surface would drastically warm to its peak temperature (which occurred just hours before the peak daily surface temperature at LL OP) and then quickly return to the usual ~7°C sub-surface temperature of other sites. I do not know what may of caused this, though initial thoughts are the small stream feeding the water to the WU site may of warmed in the previous evening uphill of the LL site (possibly in the sunny tundra above LL), resulting in my sensor detecting the delayed appearance of this warmer water when it reached my study site hours later (warming usually started ~4:00 am). Further observations were that all other sub-surface sensors had high temperature readings for the few hours following placement, suggesting removing and replacing the talus that was dug in order to place sensors resulted in a time lag for sensors to return to a normal sub-surface temperature. Generally this was fulfilled within a few hours, but this would be something to note for those who may conduct similar studies.

Other then these aforementioned effects on my study, most of my testing relied on a small sample size. Most t-tests were run with arrays of N=5 or fewer, meaning test results were more subject to the influence of variant temperatures then what would of occurred with a larger data set. If this study were to be replicated, larger data series should be used to achieve more precise results. But, the results of this study do help to characterize the microclimates of the near- and sub-surface talus environment and show that surface features can influence the microclimates used by the pika. Regarding my hypotheses, that (1) there would be a negative correlation between temperature and elevation, resulting in higher elevation taluses being the coldest; (2) the influence of slope aspect on incident sunlight would result in colder taluses on northern slopes; (3) canopy cover would shade taluses from incident sunlight, resulting in cooler near-surface and subsurface talus temperatures, and (4) The presence of water under the talus would buffer sub-surface talus temperature variation due to the additional heat capacity of humid air; data tended to uphold hypotheses that sub-surface temperature falls with elevation, northern aspect, canopy cover and sub-surface water, but the sample size was not sufficient to reveal significant effects of these features. The exception was talus depth, which had a strong and significantly negative effect on sub-surface temperatures recorded during the summer. My first hypothesis regarding overwinter temperature sensor placements, that the reduction in convective heat loss and additional heat storage vegetation provides would cause canopy-covered surfaces to be warmer than meadow surfaces, showed some support through the initial results that showed CC surfaces to be 0.65°C warmer then meadow surfaces and that meadow surfaces underwent a much larger CV of temperature fluctuations compared to CC surfaces. But the largely insignificant result of the paired t-test comparing Meadow surfaces to CC surfaces ($p = 0.3863$) does not allow me to fully accept this hypothesis. Likewise, my second hypothesis that the air-filled voids within the talus would cause talus surfaces to exhibit significantly different overwinter temperatures than those of adjacent meadows or canopy covered surfaces was not fully supported throughout individual transects or combinations of meadow and canopy covered surfaces at each study locations (WK, LL, or ML), but across all sites (therefore using the largest sample size) the difference was apparent ($p = 0.041$; difference between average covariance across all sites = 4.92). Together, there seemed to be a trend that each of this study's hypotheses might be upheld although statistical significance for each was lacking. What to do next is incorporate more data into a similar study and hopefully find concrete results instead of trends.

Conclusion and Recommendations in the Context of Environmental Studies

The future of the American Pika has become a prominent issue within current conservation biology. Some have referred to the pika as the "canaries in the coal mine" for climate change, where their alpine-specific traits make them especially susceptible to any changes in the climate of their home (Krajick, 2004). The effects of elevation, which were initially thought to provide a suitable refuge to alpine biota, may unfortunately be unable to shield these environments and their species from future warming (Walther et al., 2002; Fountain et al., 2012). Current models of pika persistence have related climate warming to definitive range retraction throughout the American West, to the extent that some have called for the species to protection under the Endangered Species Act (Wolf et al. 2007). If fulfilled, this would make the pika the first species in the lower 48 states to become protected as a direct result of anthropogenic climate change (Holtcamp, 2010).

As such, a pika's charismatic appearance and understood susceptibility to climate change can make the species a "face" for the effects of climate change much like that of the polar bear. But, because of their extended habitat throughout much of America's National Parks and Wilderness Areas, pikas may provide environmentalists and park employees a better way of communicating our impact on Earth's biota to visitors than through lectures or pamphlets on a distant arctic species. Since the reaction of pika to changes in the mountain environment can be readily visible to visitors of parks throughout the Rocky Mountains, they can provide a "close-to-home" account of climate change that may be better understood. If given enough support, this idea could help to provide the initiative and support needed for the National Park Service (NPS) to begin implementing their influence on public policies. The NPS has a duty to "conserve the scenery and the natural and historic objects and the wildlife therein and to provide for the enjoyment of the same in such manner and by such means as will leave them unimpaired for the enjoyment of future generations" (NPS, 2014) and climate change is a distinct hurdle in obtaining this goal. Because the NPS is a federal entity, they have the ability to influence public policies that help to fulfill their mission statement. In order to preserve the environments the NPS was created to protect, environmental regulation must be set into place to ensure the persistence of species like the pika in mountainous national parks.

Because as it stands today, it’s unlikely our children are going to enjoy the same extent and species composition of alpine areas that we are accustomed to today.

In 2009, the US Fish & Wildlife Service listened to the calls of researchers and conducted their own twelve-month study on the state of the American pika in the intermountain west. This has likely been the most comprehensive review yet on the current standing of the pika and provides a basis on which future research should be directed. This report concluded that there were currently enough safely established pika populations within western mountains to hold the species from endangerment into the foreseeable future and underlined the importance of understanding what makes these populations persist, so that any plans regarding the long-term conservation of the species can be effective (United States Fish and Wildlife Service, 2010). In order to do this, researchers will have to improve the metrics that have been used to model the pika’s future range and better predict which populations may be at risk. The work of Wilkening et al. (2013) developed one such metric, where the measurement of stress hormone concentration in fecal deposits can determine at-risk populations.

Extending the methods of current projections to include ways of determining acceptable sub-surface refuges will further help to improve our understanding of future pika persistence. Beyond the usual effects of aspect and elevation on temperature, reviewing my results showed that CC surfaces received lower mean and maximum temperatures and higher minimum temperatures than those of OP talus as well as suggesting that sub-surface water presence can either warm the subsurface (shown at LL) or regulate temperature (shown at ML). In times of heat stress, northern-aspect taluses that provide CC the WU temperature trend seen at ML will have habitat most conductive to pika thermoregulation at low elevation sites. Deeper taluses will also be more conductive to pika survival, as deeper voids result in colder sub-surface temperatures (see Figure 6). Come winter, the taluses directly adjacent to vegetation may have warmer temperatures, due to the heat capacity of vegetation in the winter as well as the greater accumulation of snow and thus better insulation from vegetation-induced snowdrifts. Meadow taluses did not receive this effect in my study and could receive cooler overwinter temperatures from wind-induced snow removal. Further, the overwinter temperature variation of meadow taluses could be more extreme from the effects of differential snowcover on the convective and pressure induced currents that move air throughout the talus' sub-surface voids. Ideally, temperatures of the buried talus would remain around 0°C, but incoming currents of colder air could create problematic temperature variations for pikas looking for refuge under the snowpack.

With more research, these results can provide the knowledge needed for conservationists and researchers to identify at-risk pika populations and better estimate the future boundaries of the pika's range. Although elevation can certainly provide a refuge for these species, there is a limit to which they can move uphill. With each year of increasing warmth and decreasing cold, the "sky islands" that pikas inhabit shrink and near their ultimate end at the top of each mountain peak. Without acting to change the current trends of anthropogenic climate change, our future generations may unfortunately witness the last of the American Pika's refuge disappear into the sky.

Acknowledgements

This study and my ability to have the opportunity of graduating with honors would not have been possible without the help and funding of the Biological Sciences Initiative's BURST Grant in the summer of 2013 as well as the many hours of assistance from my advisors. I would like to thank Dr. Chris Ray, Rob Guralnick, and Dale Miller for pushing me to do more with my education at the University of Colorado at Boulder and realize my academic potential. This was a great learning process for me and I'm glad to have shared it with people who are incredibly passionate at what they do. Thank you!

Image 1: A pika in the process of haying.
Photo credit:
http://ferrebeekeeper.wordpress.com/2011/01/31/the-pika/

Appendix

Figures

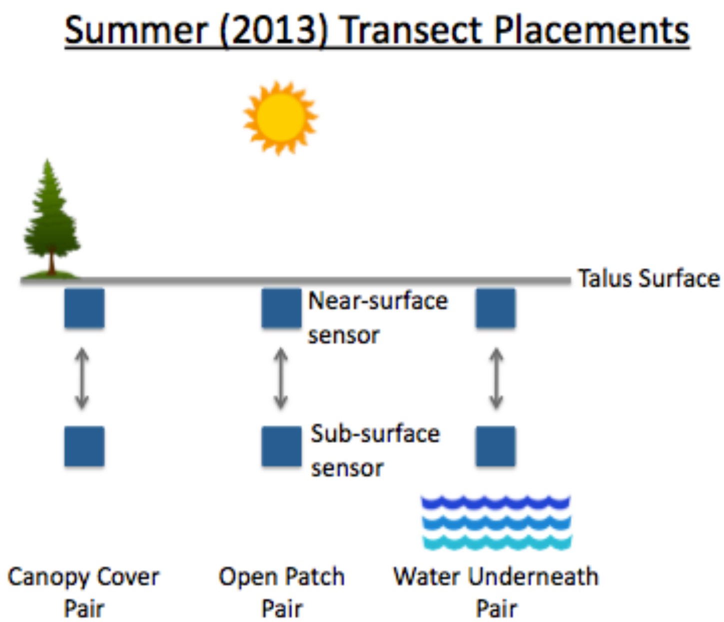

Figure 1: Summer Temperature sensor configuration. Each placement consisted of a near-surface and sub-surface temperature sensor pair.

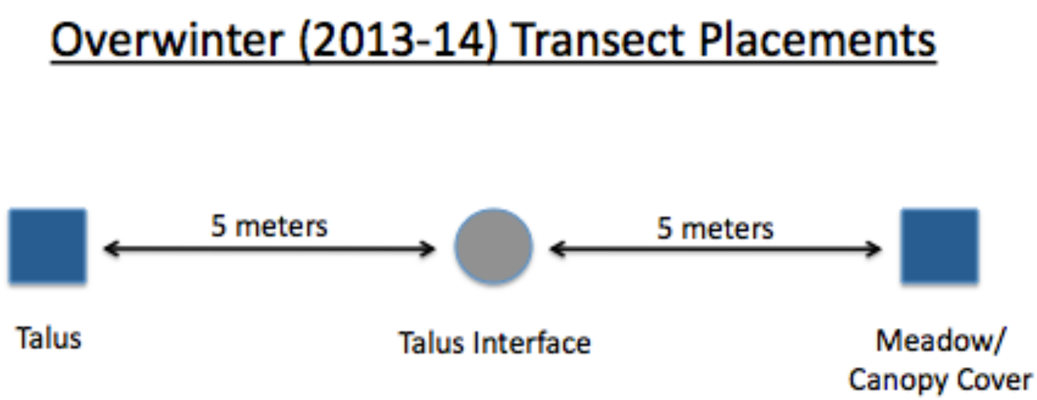

Figure 2: Overwinter transect configuration. Squares refer to temperature-only sensors while the middle circle refers to the center talus interface temperature/light sensor used to detect full snow melt-out in the middle of each transect.

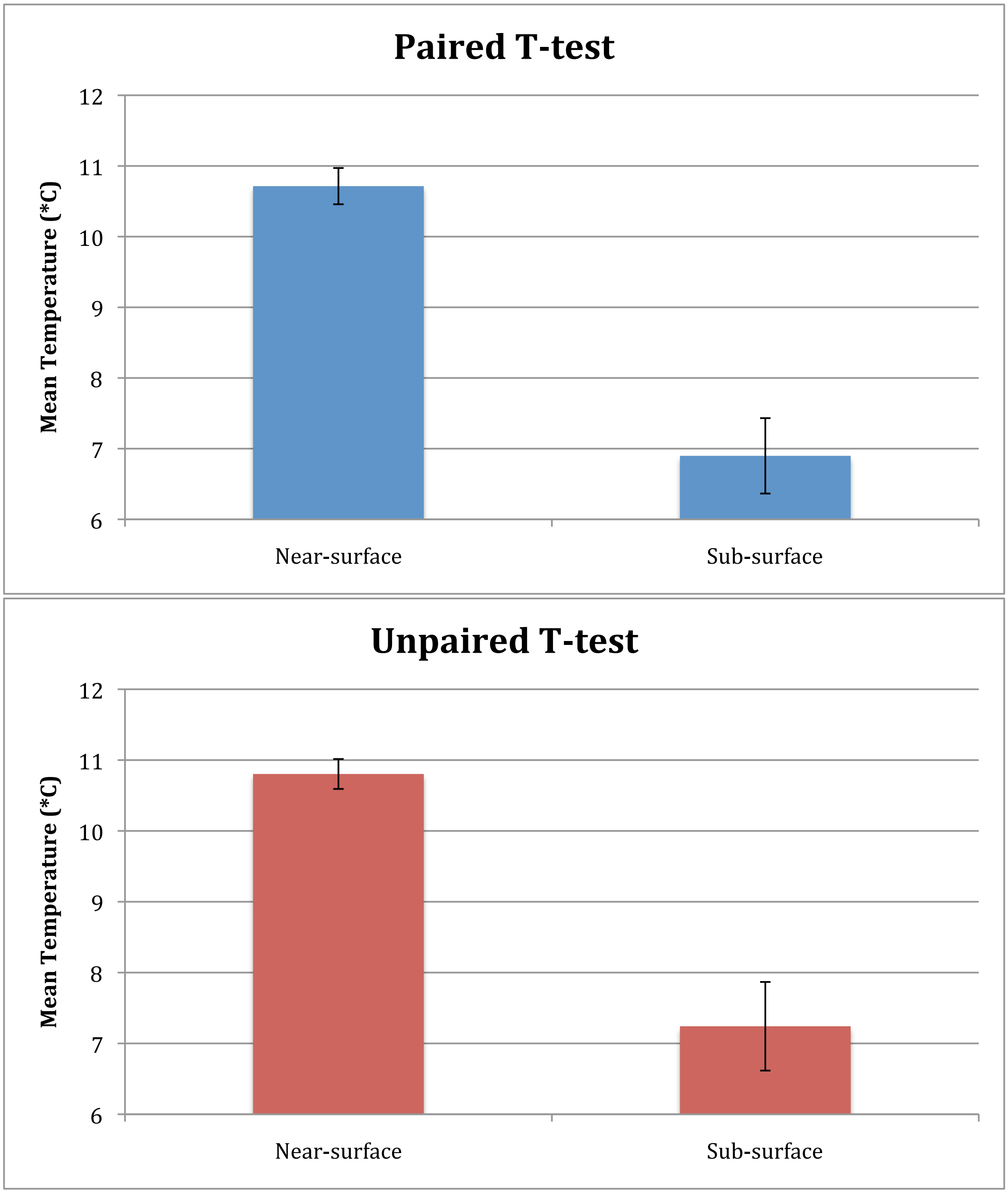

Figure 3: Bar graphs of mean temperatures of the near-surface and sub-surface used in the paired and unpaired t-test datasets. The unpaired t-test dataset used placements that had complete surface and sub-surface data values for each site whereas the unpaired t-test dataset was comprised of all sensor data, regardless of failures that occurred. Error bars are given, showing the significant difference between near-surface vs. sub-surface placement (one-tailed, paired t-test, N=12, p= 2.40 e-6; one-tailed, unpaired t-test, near-surface N=15, sub-surface N=14, p= 3.057 e-5).

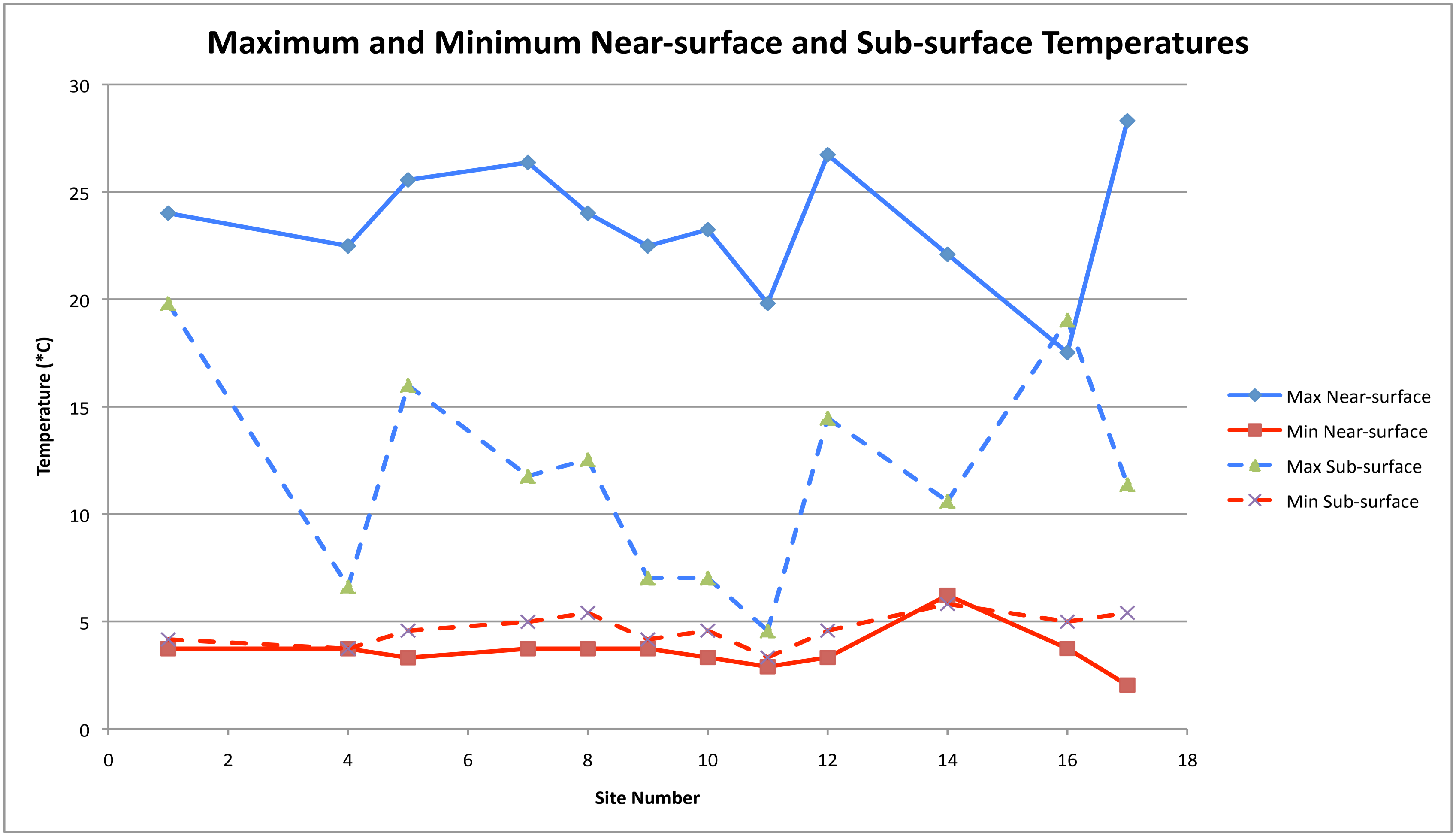

Figure 4: Compilation of summer 2013 analysis maximum and minimum temperatures for each sensor. Only sites with full near-surface and sub-surface datasets were included. Site numbers correspond to the number assignments of Table 1.

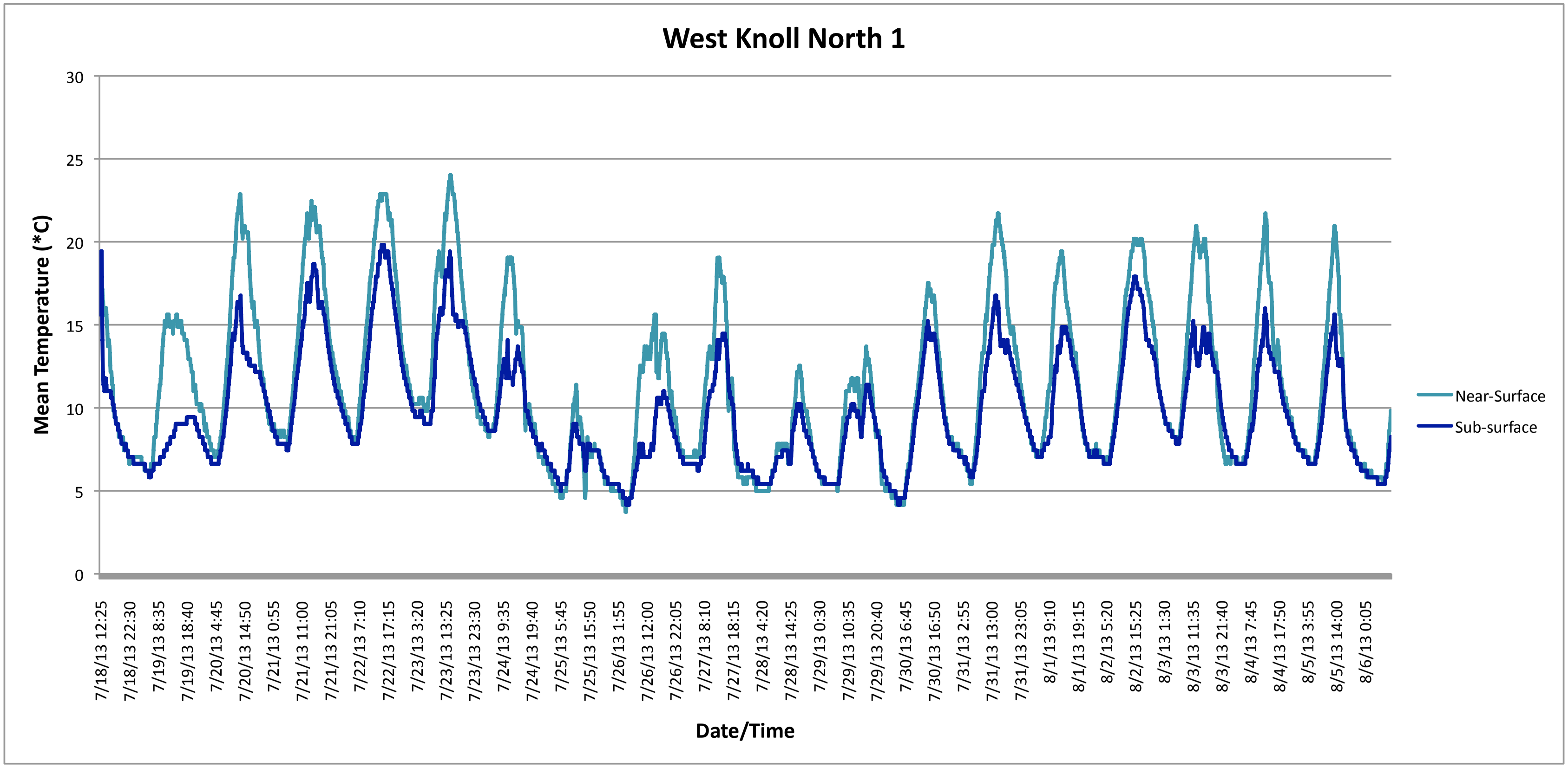

Figure 5: a) Time chart showing the daily fluctuation of near-surface and sub-surface temperatures measured at the West Knoll Northern Transect #1 site during summer 2013 placement.

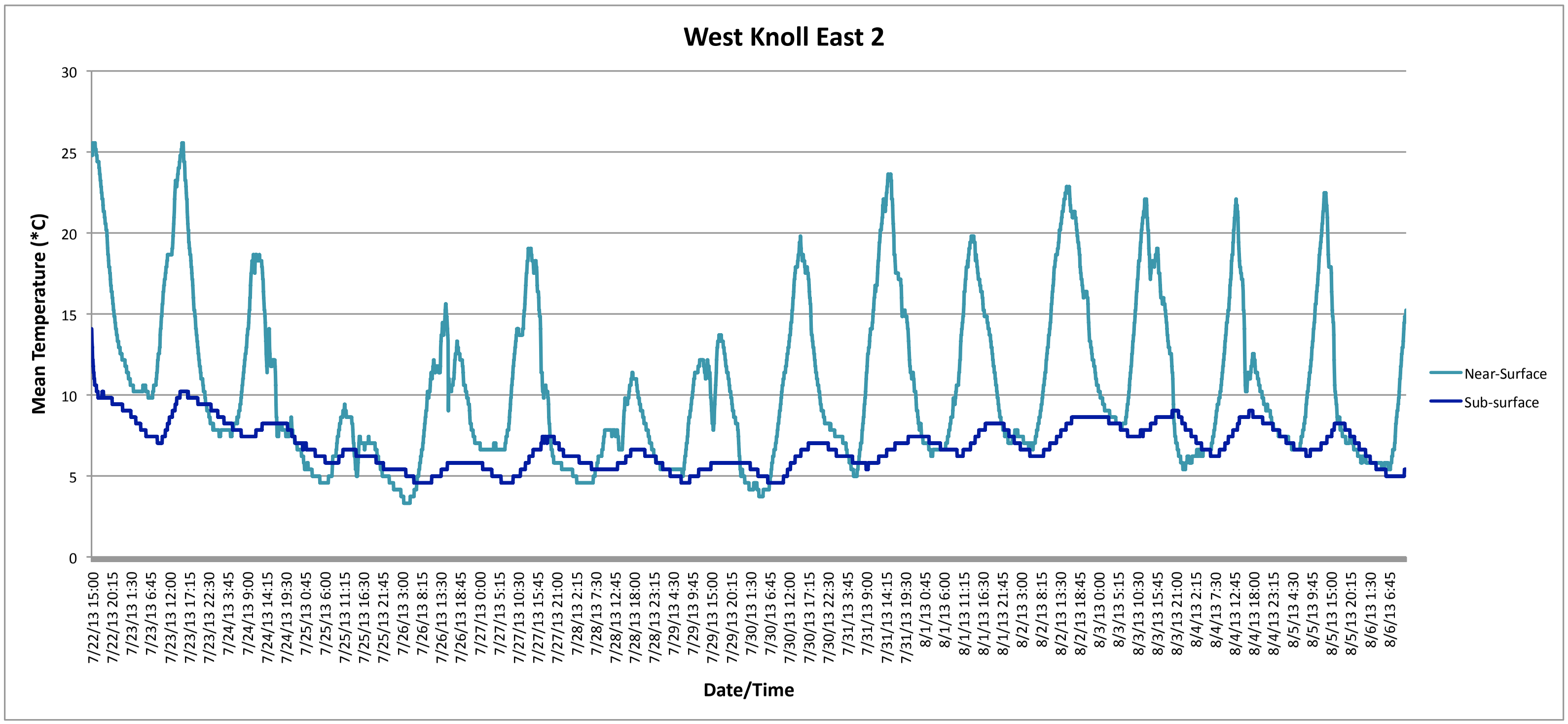

Figure 5: b) Time chart showing the daily fluctuation of near-surface and sub-surface temperatures measured at the West Knoll Eastern Transect #2 site during summer 2013 placement.

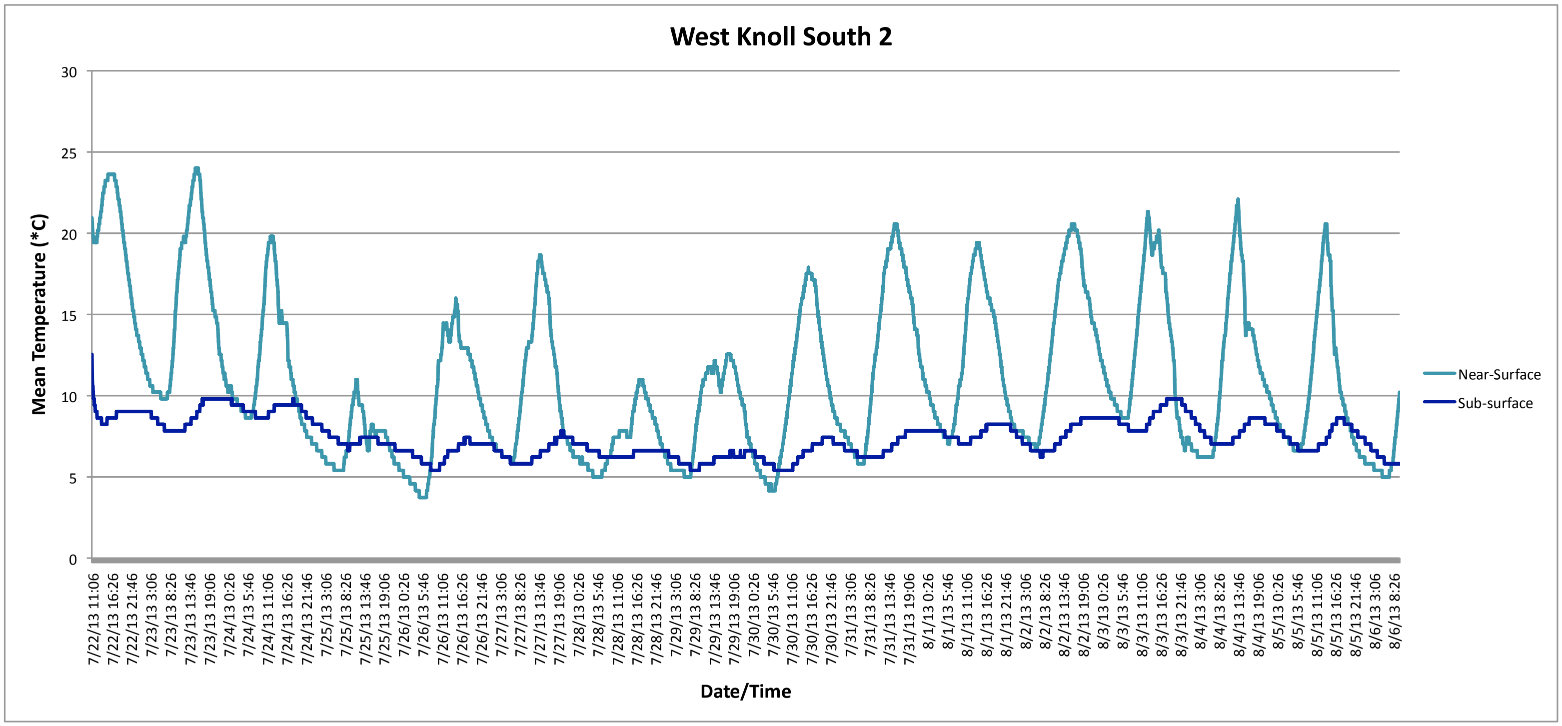

Figure 5: c) Time chart showing the daily fluctuation of near-surface and sub-surface temperatures measured at the West Knoll Southern Transect #2 site during summer 2013 placement.

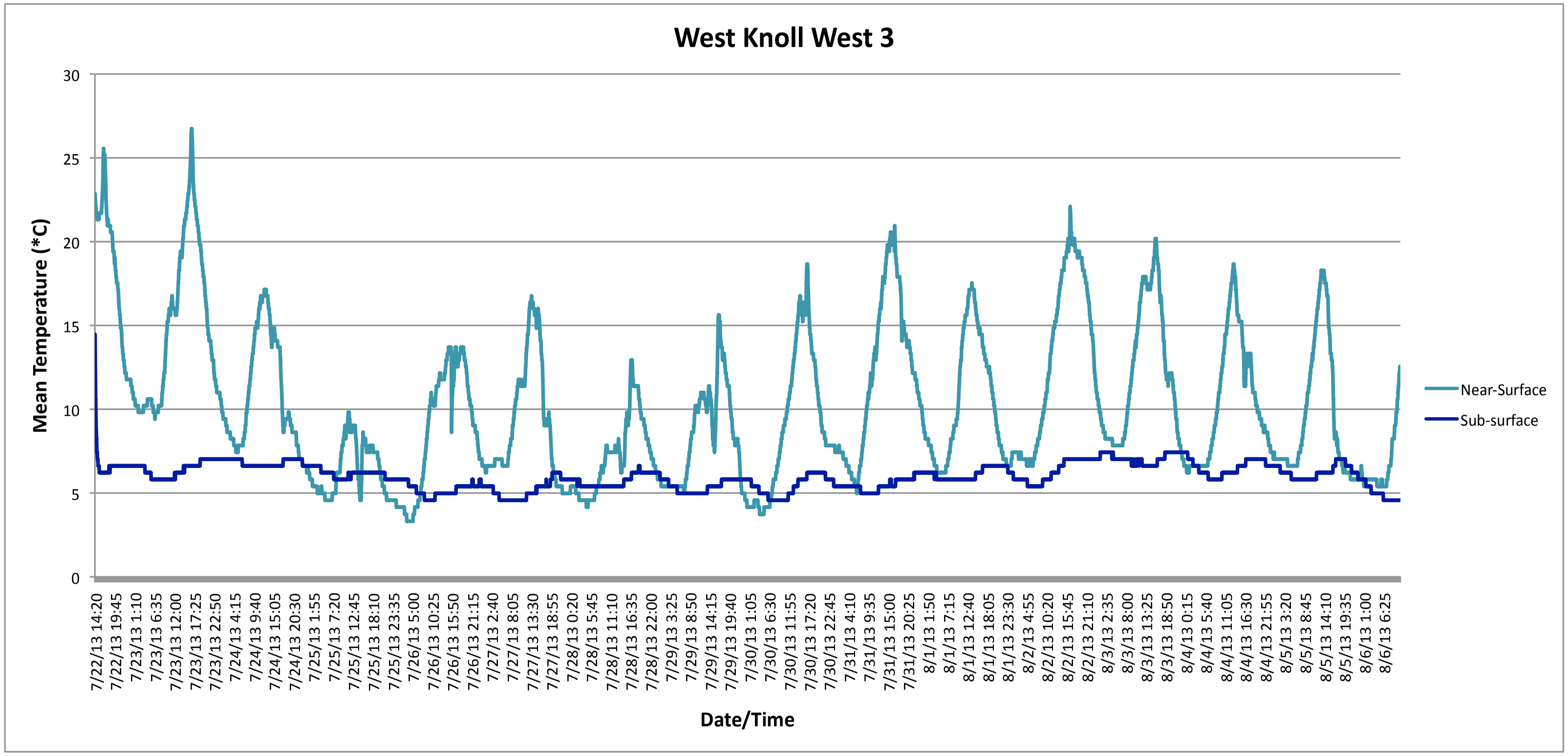

Figure 5: d) Time chart showing the daily fluctuation of near-surface and sub-surface temperatures measured at the West Knoll Western Transect #3 site during summer 2013 placement.

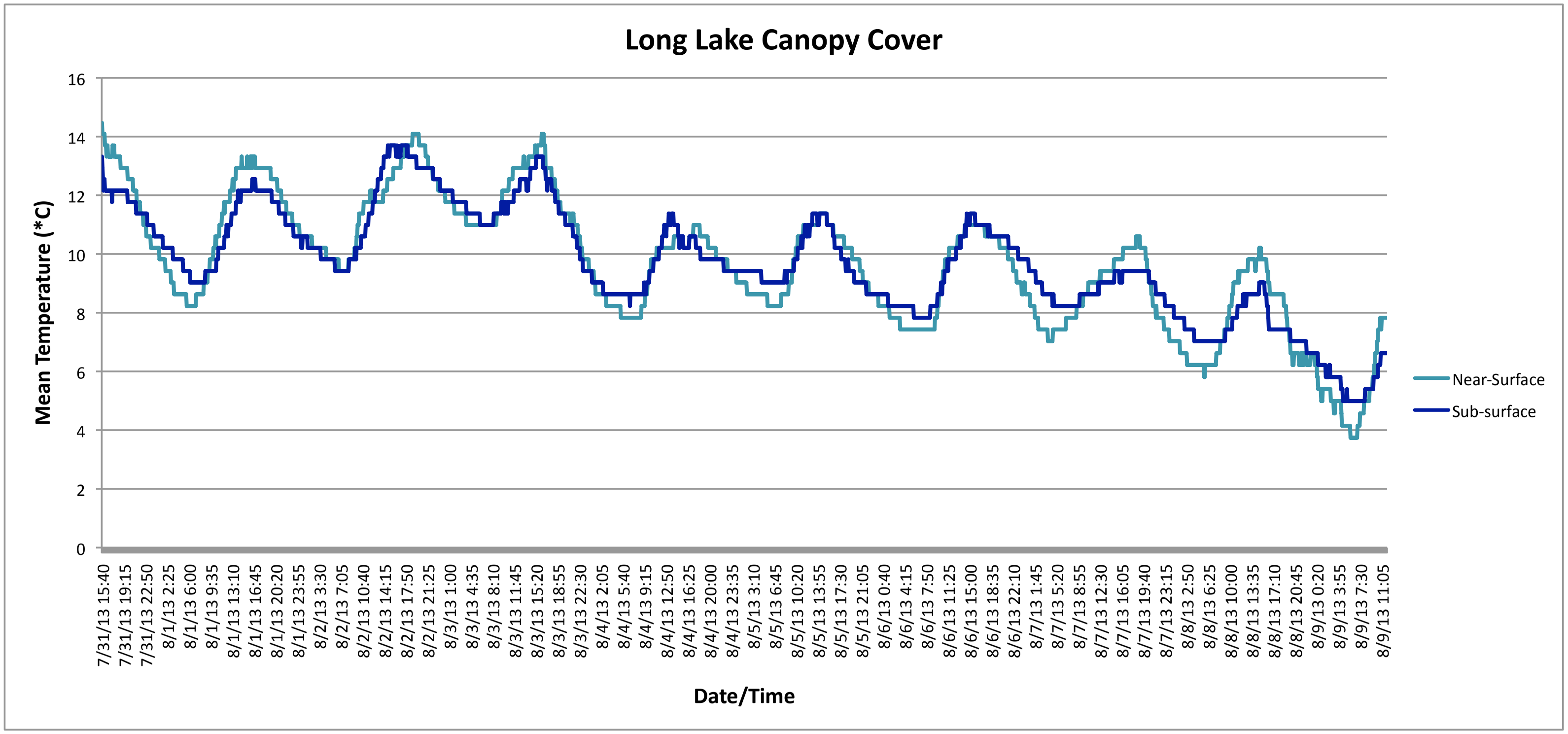

Figure 5: e) Time chart showing the daily fluctuation of near-surface and sub-surface temperatures measured at the Long Lake Canopy Cover transect site during summer 2013 placement.

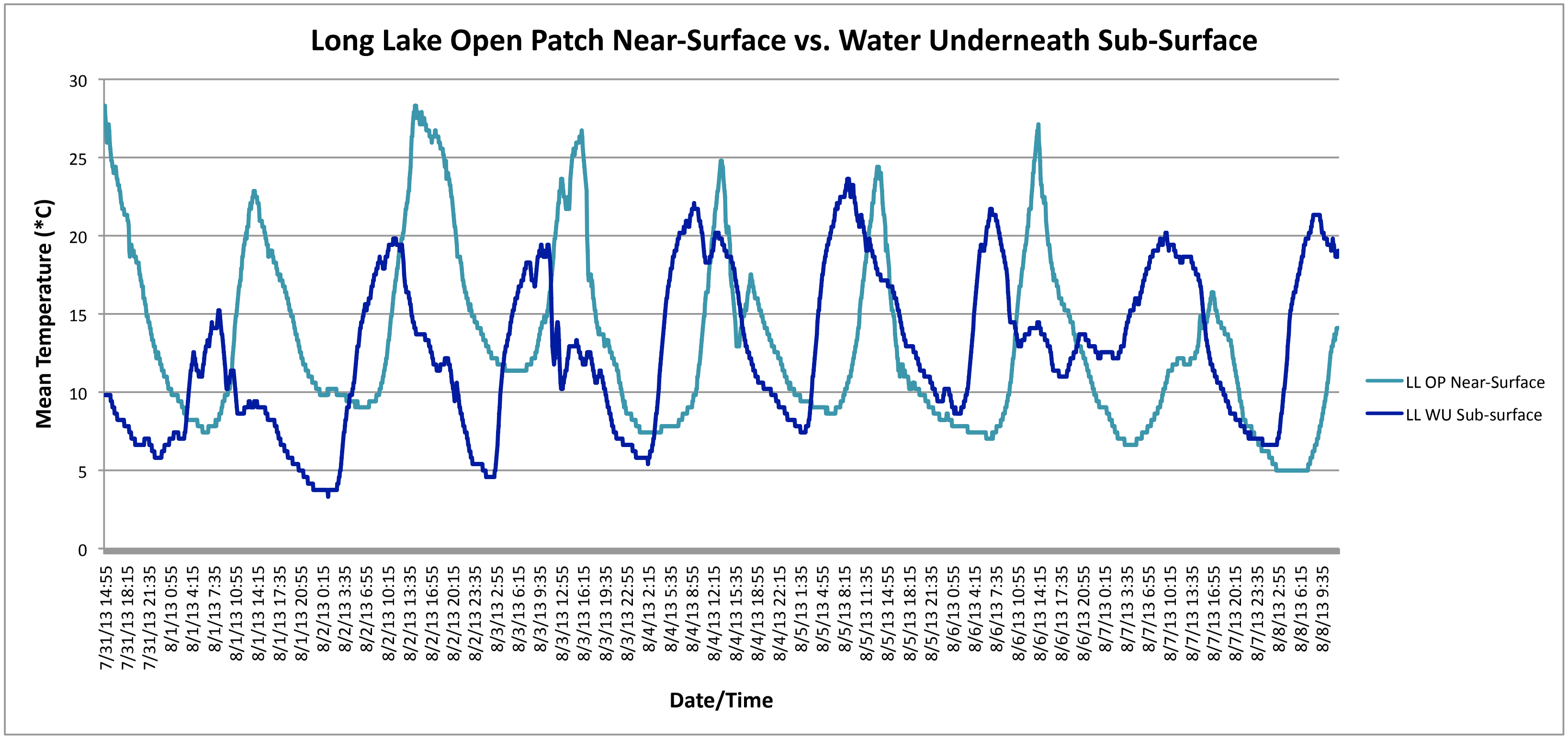

Figure 5: f) Time chart showing the daily fluctuation of Open Patch near-surface and Water Underneath sub-surface temperatures measured at Long Lake during summer 2013 placement. Open patch near-surface temperature data was used for comparison because the near-surface water underneath sensor failed. Note the large spikes in sub-surface temperature and how sub-surface maximums occur before those of the near-surface data.

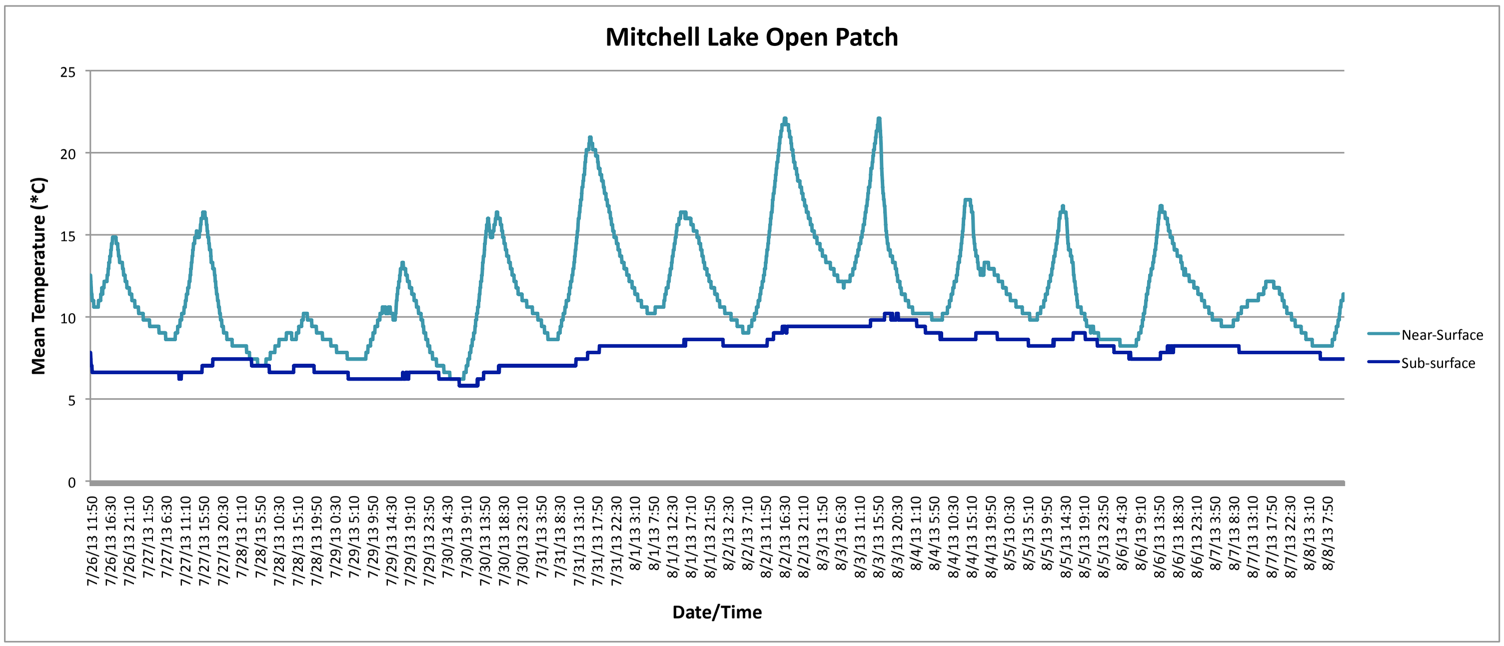

Figure 5: g) Time chart showing the daily fluctuation of near-surface and sub-surface temperatures measured at Mitchell Lake Open Patch transect site during summer 2013 placement.

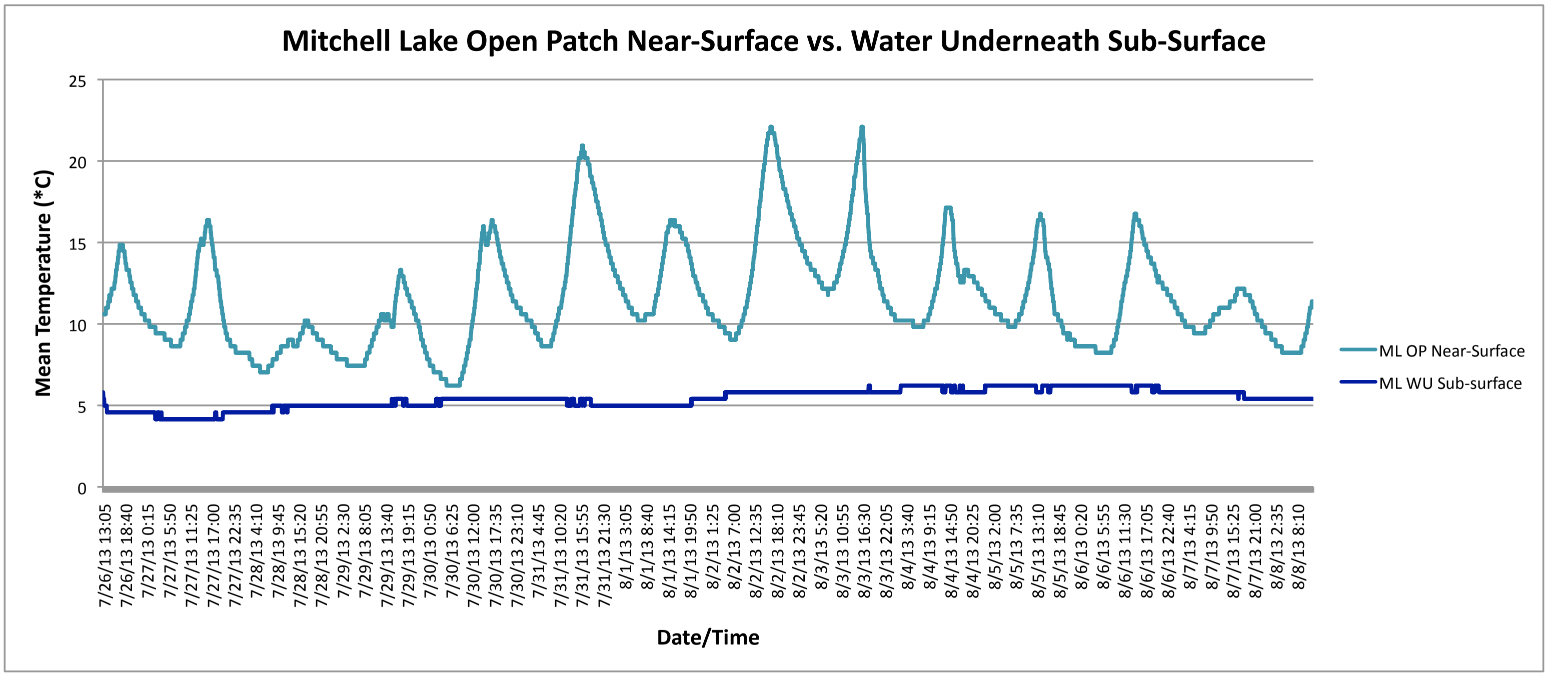

Figure 5: h) Time chart showing the daily fluctuation of Open Patch near-surface and Water Underneath sub-surface temperatures measured at Mitchell Lake during summer 2013 placement. Open patch near-surface temperature data was used for comparison because the near-surface water underneath sensor failed.

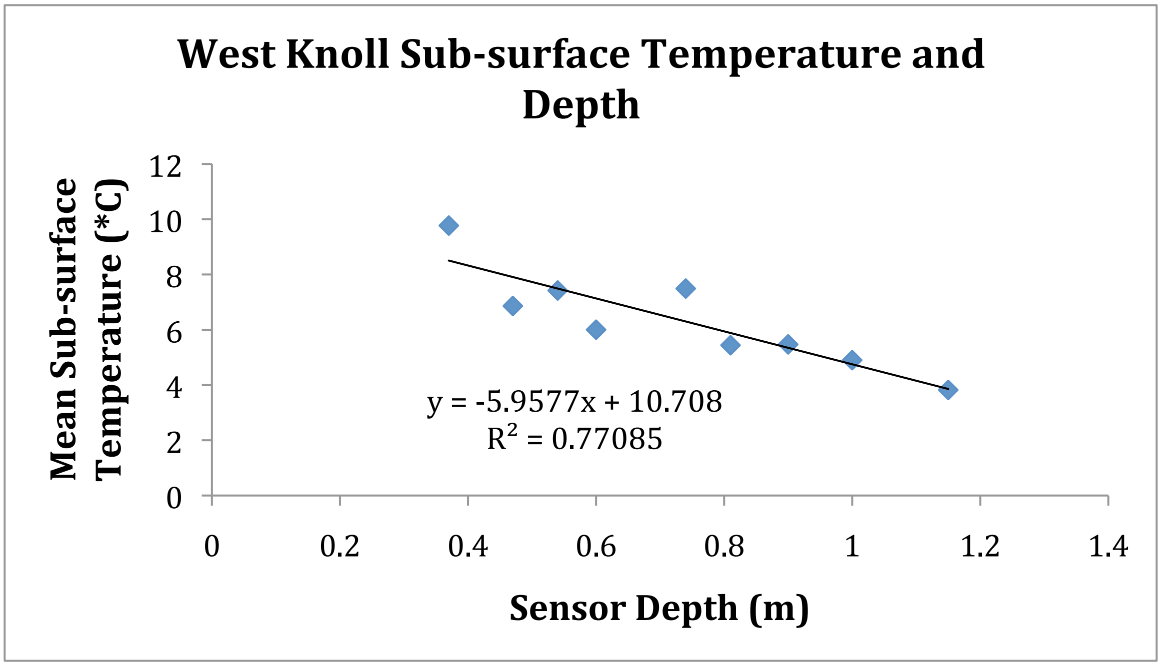

Figure 6: Regressing mean sub-surface temperature against sub-surface sensor depth on the West Knoll with summer 2013 data. The slope of the regression line is an estimate of the degree of cooling West Knoll taluses provided during sensor placement (-5.95°C/ meter). R^2 = 0.77

Figure 7 a)

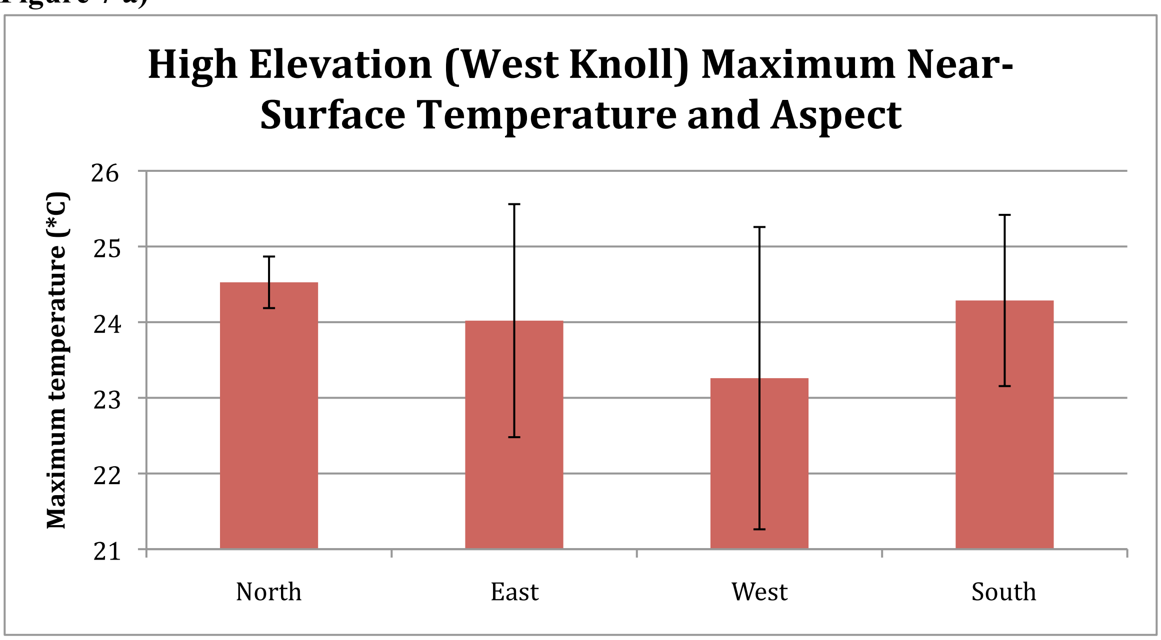

Figure 7 b)

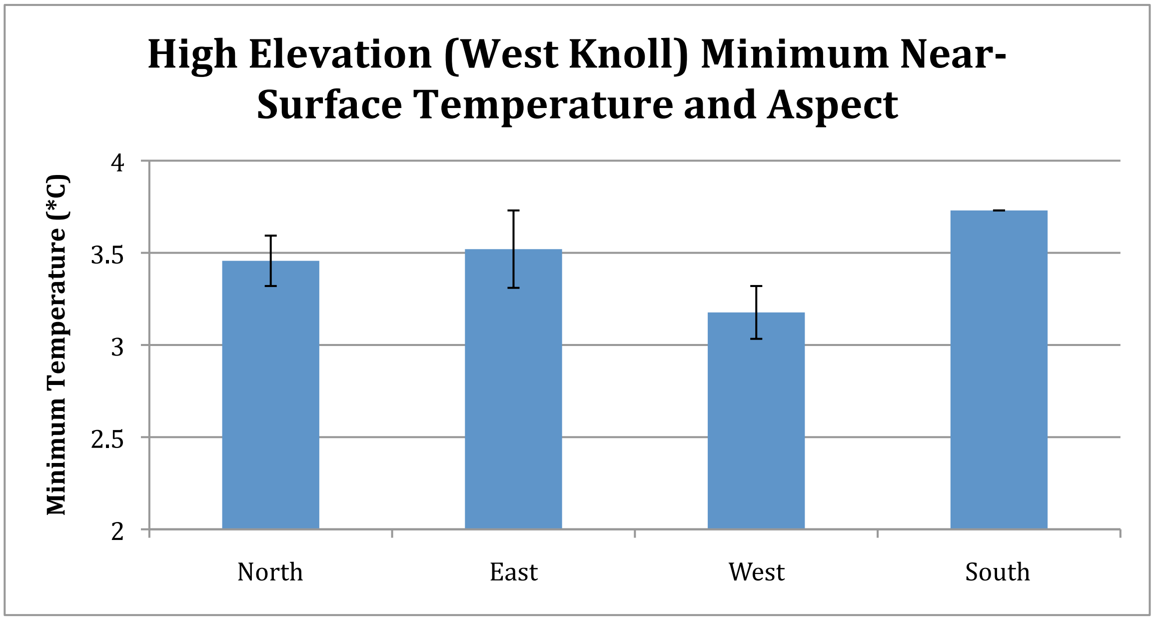

Figure 7 c)

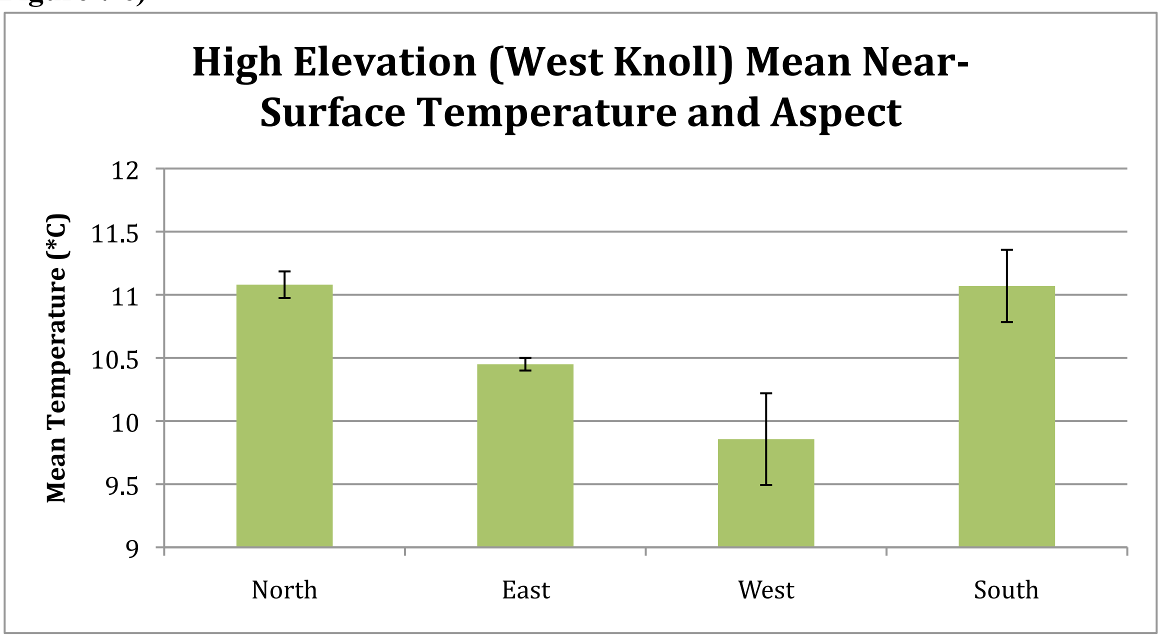

Figure 7 d)

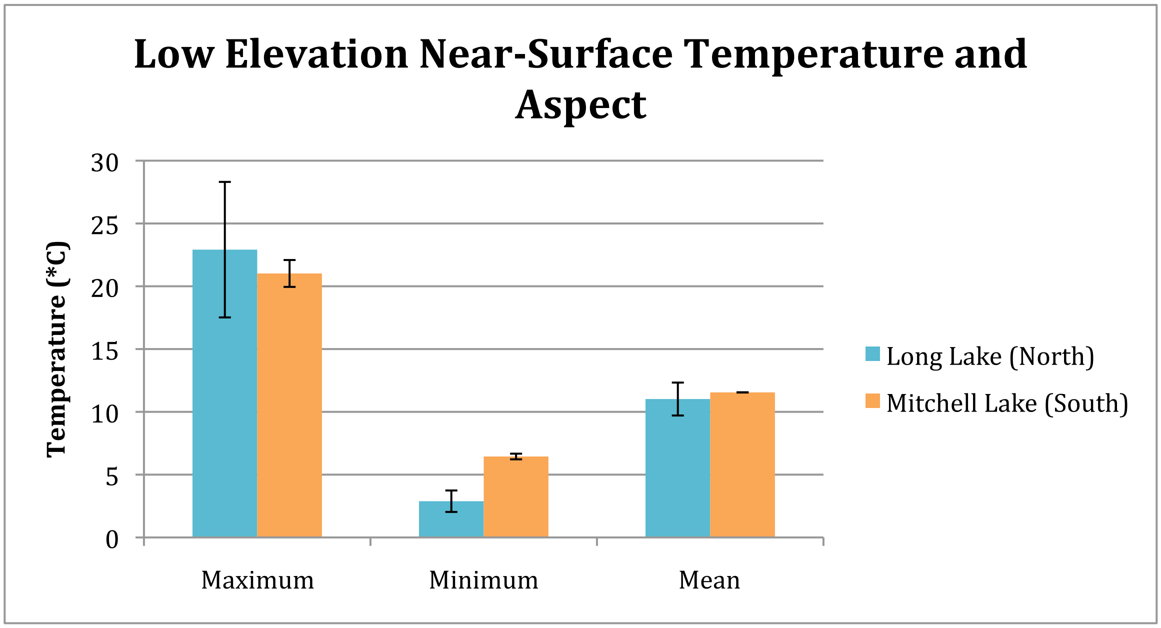

Figure 7 e)

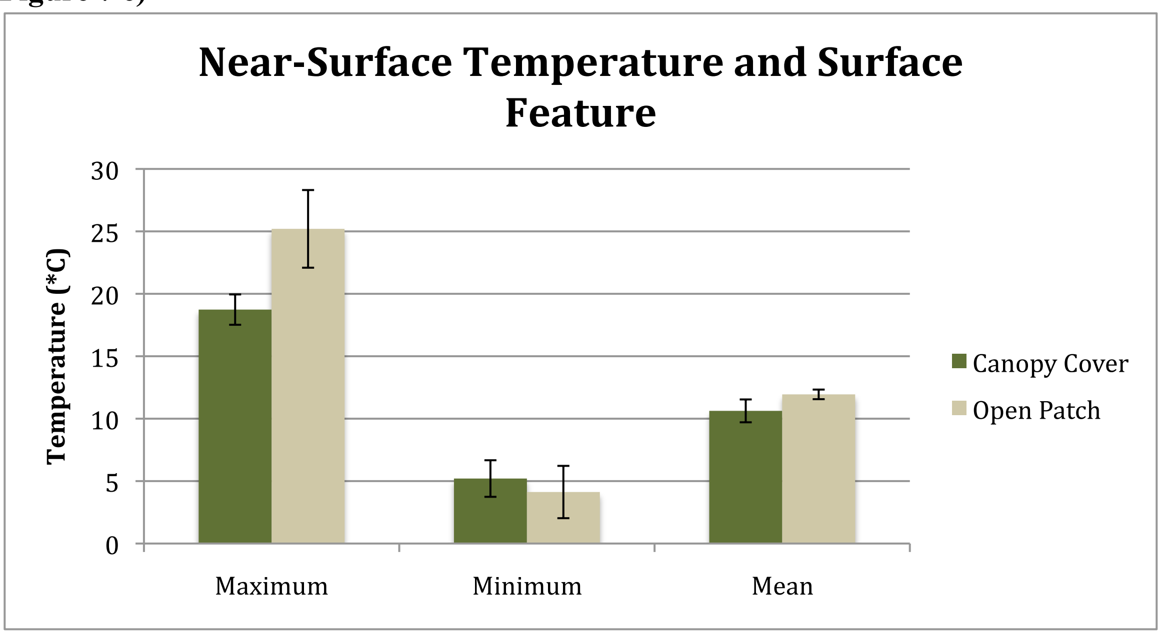

Figure 7 f)

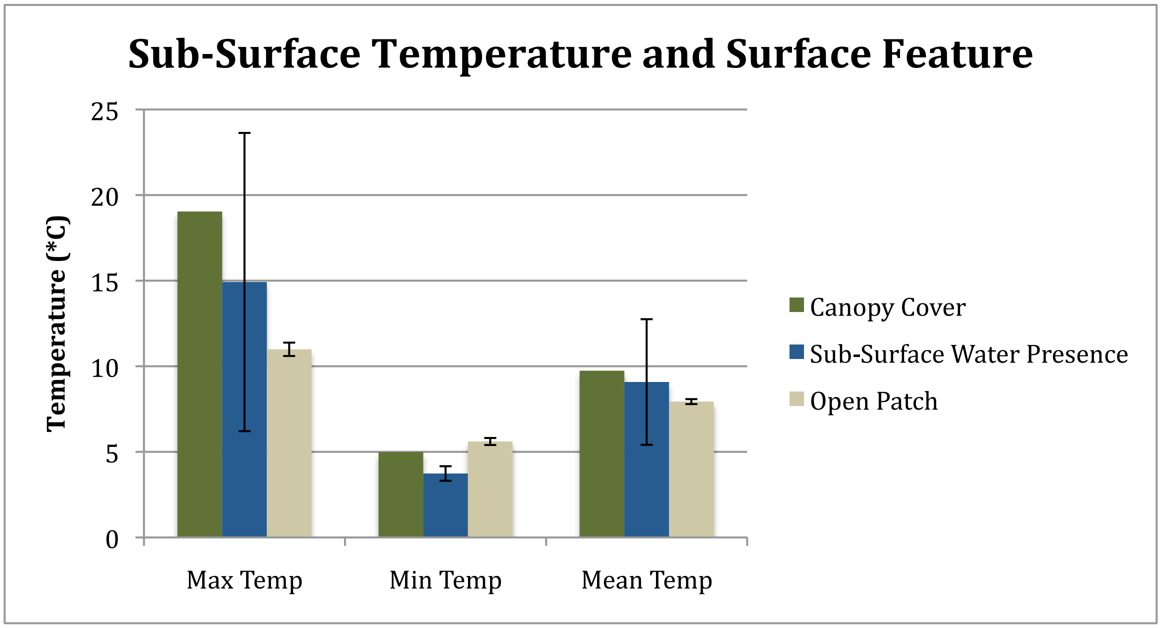

Figure 7: Bar chart summaries of maximum, minimum, and mean near-surface temperature (°C) during summer 2013 placement. a-c) refer to mean temperature with aspect at the high elevation West Knoll site while d) compares maximum, minimum, and mean temperature with aspect between the low-elevation Long Lake and Mitchell Lake sites. e-f) compare maximum, minimum, and mean temperatures with the studied surface features (canopy cover, sub-surface water presence, and open patch talus) at Long Lake and Mitchell Lake.

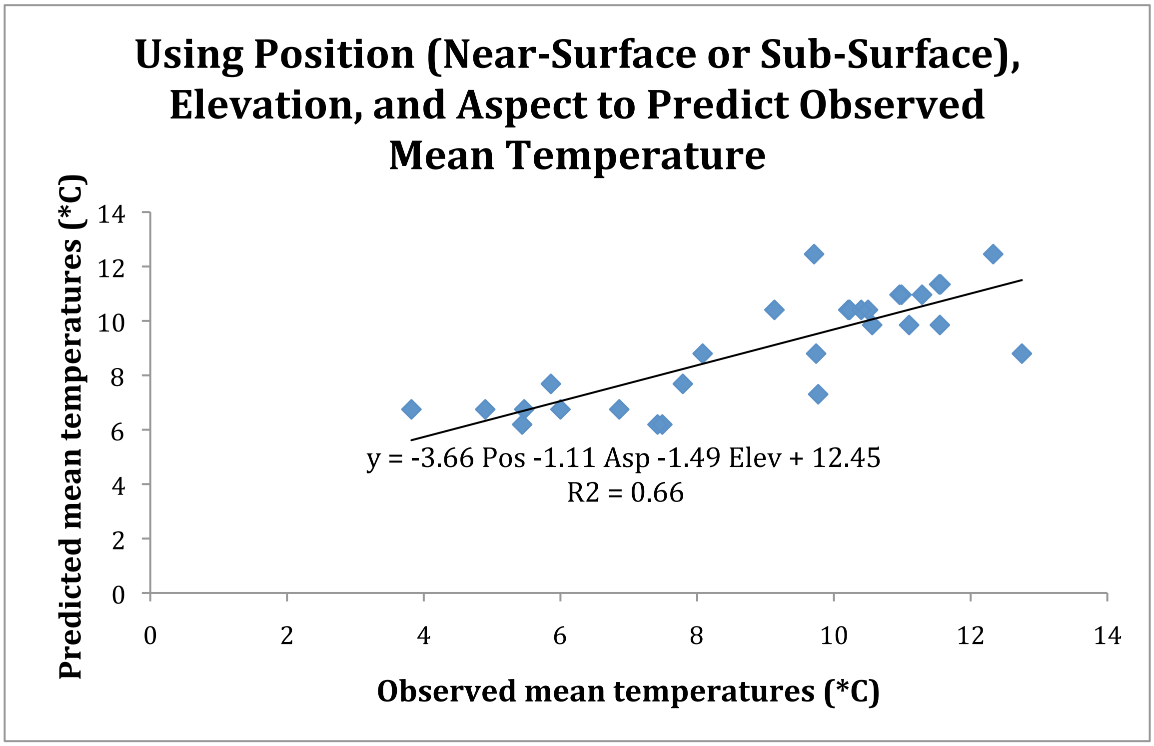

Figure 8: Linear Regression using placement (near-surface vs. sub-surface), elevation, and aspect to predict observed mean temperatures. R^2 = 0.66

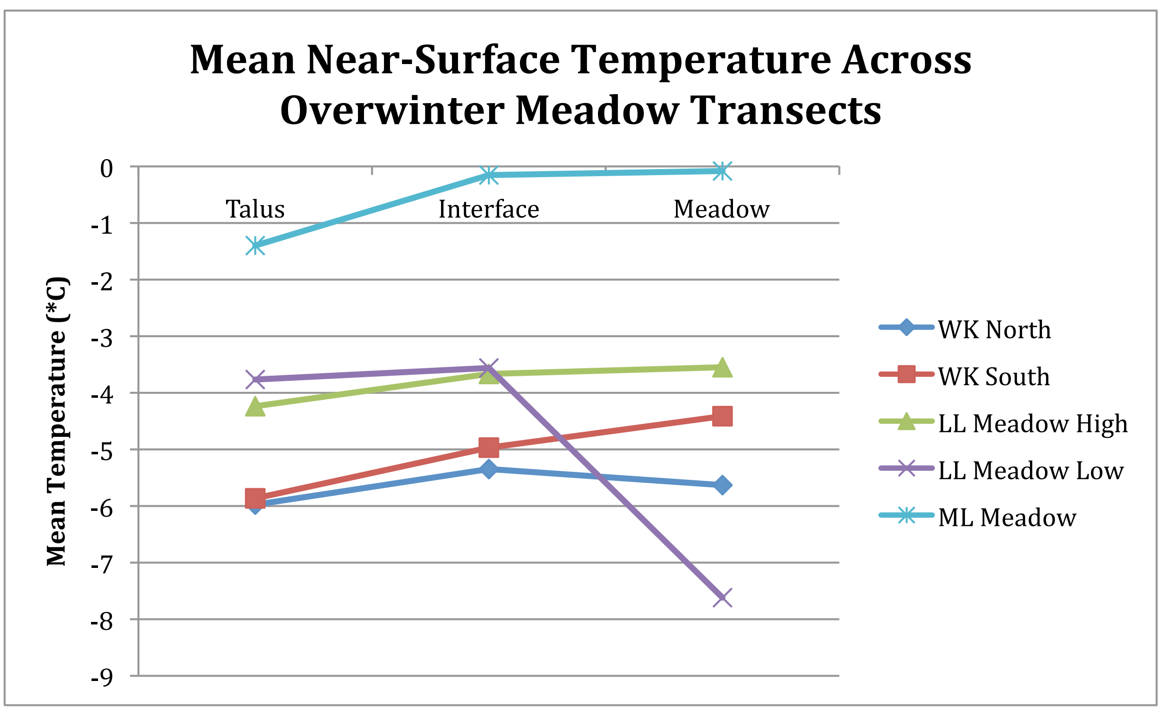

Figure 9: Recorded mean temperatures across overwinter meadow transects at all sites.

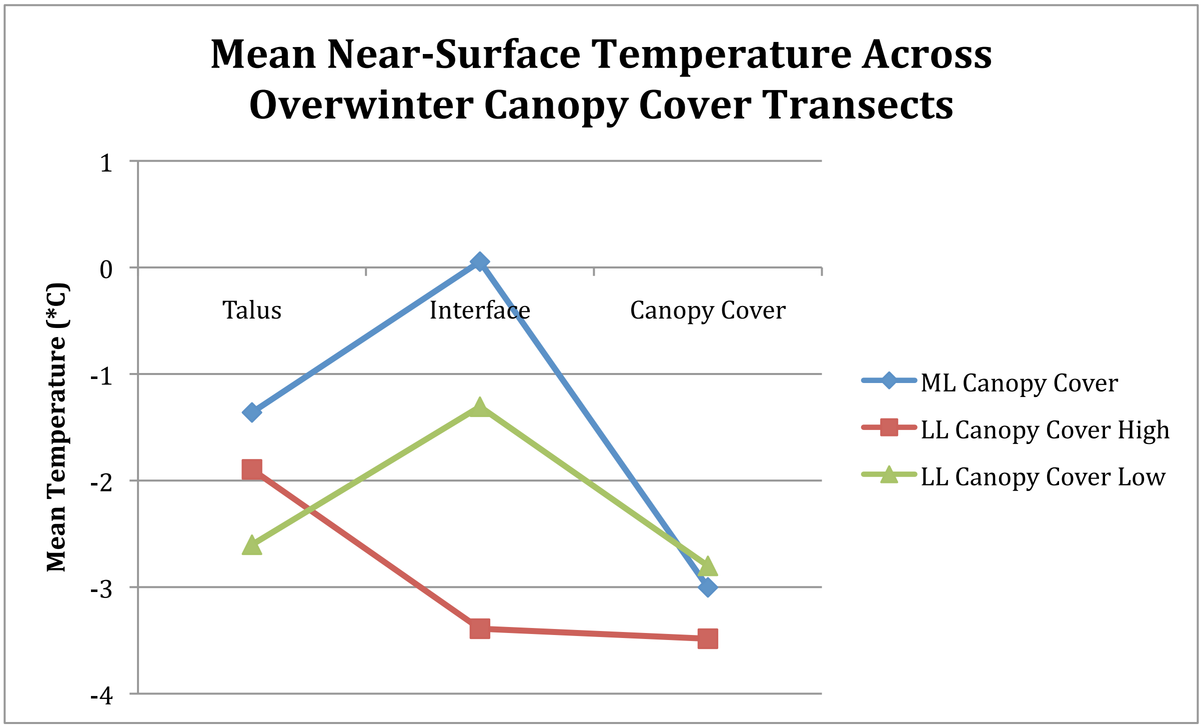

Figure 10: Recorded mean temperatures across overwinter canopy cover transects.

Tables

Table 1: Summary of initial data logger data for summer 2013 placements. Corresponding abbreviations are WK = West Knoll, ML = Mitchell Lake, LL = Long Lake, CC = Canopy Cover, OP = Open Talus, WU = Water Underneath Talus

Site Number	Location	Max Near-Surface Temp (°C)	Min Near-Surface Temp (°C)	Mean Near-Surface Temp (°C)	Max Subsur. Temp (°C)	Min Subsur. Temp (°C)	Mean Subsur. Temp (°C)
1	WK N1	24.01	3.73	11.29	19.81	4.16	9.77
2	WK N2	24.4	3.32	10.96	NA	NA	NA
3	WK N3	25.17	3.32	10.99	NA	NA	NA
4	WK E1	22.48	3.73	10.4	6.62	3.73	4.9
5	WK E2	25.56	3.31	10.5	16	4.57	6.86
6	WK E3	NA	NA	NA	NA	NA	NA
7	WK S1	26.37	3.73	11.55	11.77	4.98	7.49
8	WK S2	24.01	3.73	11.1	12.54	5.4	7.42
9	WK S3	22.48	3.73	10.56	7.03	4.16	5.44
10	WK W1	23.24	3.32	10.21	7.03	4.57	5.47
11	WK W2	19.81	2.89	9.13	4.57	3.32	3.82
12	WK W3	26.73	3.32	10.23	14.47	4.57	6
13	ML CC	19.95	6.67	11.54	NA	NA	NA
14	ML OP	22.09	6.22	11.56	10.6	5.81	7.79
15	ML WU	NA	NA	NA	6.22	4.16	5.42
16	LL CC	17.52	3.74	9.71	19.04	4.99	9.74
17	LL OP	28.31	2.03	12.33	11.38	5.4	8.08
18	LL WU	NA	NA	NA	23.63	3.31	12.75

Table 2: Summary of initial data logger data for overwinter WK sites.

	West Knoll Transects			
	North		South	
Talus	Avg Temp	-5.975783133	Avg Temp	-5.8643473
	Max Temp	21.71	Max Temp	18.28
	Min Temp	-19.49	Min Temp	-20.24
	VAR	52.06995842	VAR	30.5741992
	ST DEV	7.215951665	ST DEV	5.52939411
	Hours >25C	0	Hours >25C	0
	Hours <-10C	1547	Hours <-10C	1150
Talus Intfce	AVG Temp	-5.3472473	Avg Temp	-4.9686357
	Max Temp	19.092222	Max Temp	17.665
	Min Temp	-22.092222	Min Temp	-17.792222
	Var	52.4257165	VAR	17.5820486
	St DEV	7.24056051	ST DEV	4.19309535
	Hours >25C	0	Hours >25C	0
	Hours <-10C	1185	Hours <-10C	601
Meadow	Avg Temp	-5.6306736	Avg Temp	-4.4132044
	Max Temp	19.81	Max Temp	-0.16
	Min Temp	-24.3	Min Temp	-14.73
	VAR	58.7961355	VAR	10.0396762
	ST DEV	7.66786381	ST DEV	3.1685448
	Hours >25C	0	Hours >25C	0
	Hours <-10C	1496	Hours <-10C	340
Appx. Meltout	April 16th		June 22nd	

Table 3: Summary of initial data logger data for overwinter LL sites.

	Long Lake Transects			
	Meadow High		Meadow Low	
Talus	Avg Temp	-4.23673673	AVG Temp	-3.7652539
	Max Temp	33.17	Max Temp	23.63
	Min Temp	-19.49	Min Temp	-13.49
	VAR	51.48914367	VAR	40.3891494
	ST DEV	7.175593611	ST DEV	6.35524582
	Hours >25C	18	Hours >25C	0
	Hours <-10C	1049	Hours <-10C	399
Talus Intrfce	Avg Temp	-3.6663827	Avg Temp	-3.5608317
	Max Temp	36.0788889	Max Temp	27.2722222
	Min Temp	-22.092222	Min Temp	-17.617778
	VAR	56.075049	VAR	47.8531157
	ST DEV	7.48832752	ST DEV	6.91759465
	Hours >25C	15.5	Hours >25C	6
	Hours <-10C	884.5	Hours <-10C	720
Meadow	Avg Temp	-3.547809	Avg Temp	-7.6190503
	Max Temp	24.01	Max Temp	4.5
	Min Temp	-20.24	Min Temp	-17.9
	VAR	45.3964198	VAR	10.5205145
	ST DEV	6.73768653	ST DEV	3.24353426
	Hours >25C	0	Hours >25C	0
	Hours <-10C	831	Hours <-10C	770
Appx. Meltout	Off/On - 1 month burials		Off/on - 1 month burials	
	Forest High		Forest Low	
Talus	Avg Temp	-1.8953776	AVG Temp	-2.6020467
	Max Temp	42.94	Max Temp	40.59
	Min Temp	-9.46	Min Temp	-14.73
	VAR	37.1459493	VAR	49.609805
	ST DEV	6.09474768	ST DEV	7.04342282
	Hours >25C	0	Hours >25C	0
	Hours <-10C	0	Hours <-10C	311
Talus Intrfce	Avg Temp	-3.3904119	Avg Temp	-1.306819
	Max Temp	18.6161111	Max Temp	18.9011111
	Min Temp	-12.956111	Min Temp	-4.88
	VAR	26.2388249	VAR	8.98360724
	ST DEV	5.12238469	ST DEV	2.99726663
	Hours >25C	0	Hours >25C	0
	Hours <-10C	254	Hours <-10C	0
Forest	Avg Temp	-3.4843338	Avg Temp	-2.8002618
	Max Temp	20.57	Max Temp	19.81
	Min Temp	-11.13	Min Temp	-10.01
	Var	15.9690052	VAR	14.0316759
	St Dev	3.99612378	ST DEV	3.74588786
	Hours >25C	0	Hours >25C	0
	Hours <-10C	41	Hours <-10C	7
Appx. Meltout	May 29th		June 3rd	

Table 4: Summary of initial data logger data for overwinter WK sites.

	Mitchell Lake			
	Meadow		Air Temp (Placed in Tree: 1/6/13- 9/23/13)	
Talus	Avg Temp	-1.398381696	Avg Temp	2.13019219
	Max Temp	-0.1	Max Temp	24.3511111
	Min Temp	-1.9	Min Temp	-24.847778
	VAR	0.05109174	VAR	108.174186
	ST DEV	0.226034821	ST DEV	10.400682
	Hours >25C	0	Hours >25C	0
	Hours <-10C	0	Hours <-10C	945
Talus Intrfce	Avg Temp	-0.152929947		
	Max Temp	0.01		
	Min Temp	-0.325		
	VAR	0.003064307		
	ST DEV	0.055356185		
	Hours >25C	0		
	Hours <-10C	0		
Meadow	Avg Temp	-0.0814732		
	Max Temp	0.2		
	Min Temp	-0.6		
	VAR	0.00566438		
	ST DEV	0.0752621		
	Hours >25C	0		
	Hours <-10C	0		
Appx. Meltout	Buried for Duration of Study			
	Forest			
Talus	Avg Temp	-1.3610339		
	Max Temp	20.5		
	Min Temp	-4.8		
	VAR	1.42595021		
	ST DEV	1.19413157		
	Hours >25C	0		
	Hours <-10C	0		
Talus Intrfce	Avg Temp	0.05442692		
	Max Temp	30.0538889		
	Min Temp	-0.325		
	VAR	2.9914697		
	ST DEV	1.72958657		
	Hours >25C	7		
	Hours <-10C	0		
Forest	Avg Temp	-3.002513966		
	Max Temp	-0.6		
	Min Temp	-6.3		
	VAR	1.818143481		
	ST DEV	1.348385509		
	Hours >25C	0		
	Hours <-10C	0		
Appx. Meltout	Low cover 6/23 (6lumens)			

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